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PERVASIVE PERSONAL INFORMATION SPACES

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ABSTRACT

Each user's electronic information-interaction uniquely matches their information behaviour, activities and work context. In the ubiquitous computing environment, this information-interaction and the underlying personal information is distributed across multiple personal devices.

This thesis investigates the idea of Pervasive Personal Information Spaces for improving ubiquitous personal information-interaction. Pervasive Personal Information Spaces integrate information distributed across multiple personal devices to support anytime-anywhere access to an individual's information. This information is then visualised through context-based, flexible views that are personalised through user activities, diverse annotations and spontaneous information associations.

The *Spaces model* embodies the characteristics of Pervasive Personal Information Spaces, which emphasise integration of the user's information space, automation and communication, and flexible views. The model forms the basis for InfoMesh, an example implementation developed for desktops, laptops and PDAs. The design of the system was supported by a tool developed during the research called *activity snaps* that captures realistic user activity information for aiding the design and evaluation of interactive systems.

User evaluation of InfoMesh elicited a positive response from participants for the ideas underlying Pervasive Personal Information Spaces, especially for carrying out work naturally and visualising, interpreting and retrieving information according to personalised contexts, associations and annotations. The user studies supported the research hypothesis, revealing that context-based flexible views may indeed provide better contextual, ubiquitous access and visualisation of information than current-day systems.

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CHAPTER 1 - INTRODUCTION

This thesis investigates the concept of Pervasive Personal Information Spaces, which provides ubiquitous access to an individual's distributed information space through context-based flexible views. This concept underlies the Spaces model, a framework that forms the foundation for the InfoMesh system, an example implementation of Pervasive Personal Information Spaces. InfoMesh integrates users' multiple personal devices and assists with creating, managing, viewing, accessing and interpreting their personal distributed information space.

1.1 MOTIVATION

The use of multiple personal computing devices by individuals is steadily growing in the ubiquitous computing environment. Desktop computers, laptops, personal digital assistants and mobile phones are commonplace, and in the near future this list will include further handheld and wearable devices. These devices are used to carry out a wide range of information work, including gathering, creating, managing and sharing information, as well as communicating with others. This information work spans numerous contexts relating to user activity, time, location, people and goals, and combines computer-supported components of user activities with their real-world counterparts. The user's resulting information collection is therefore as individual as their creator, changing in composition and emphasis over time, and has a wealth of underlying information relationships that are still largely left unexplored and unutilised in electronic information management.

Over the last decade, the boundaries between the uses and support offered by the different personal devices have become blurred. The operating systems, as well as interaction and presentation options provided by the devices are starting to overlap, allowing users to access and view similar information from different devices. For example, desktop and notebook computers, PDAs and mobile phones all support forms of information access and generation, Internet access, communication and scheduling activities.

Currently the information on these devices is bridged through the use of different synchronisation technologies. However, these technologies still keep users bound to device, location and networking capabilities in their interaction with

information, and do not support a continuous work context or anytime-anywhere access to all personal, gathered information.

In the physical world, the users' information space corresponds with various physical media such as books, pictures, documents, and folders of paper stored at home and work, and the material available in the library or through other people like friends and colleagues. In the electronic world, the users' information space is defined by all the material stored and accessed from their different devices. The electronic information space an individual creates is however much larger than the physical world could ever provide for. People amass ever-larger quantities of text, images, audio and video in the electronic form. This information is gathered, created and shared rapidly within the context of various tasks or activities, resulting in a flood of information.

The last decade has seen many developments towards simplifying and assisting users in managing their information overload. These include a variety of changes to the devices themselves, their processing and storage capabilities; the interfaces, visualisation and interaction styles employed in applications; and also the processes and systems developed for information organisation and retrieval.

Research into ubiquitous and pervasive computing technologies and applications has more recently been considering how to best support human-information interaction in the changing computing environment with the proliferation of multiple personal devices, alongside work into hardware and software architectures to support anytime-anywhere access to information. Research has also emerged on personalising views of a user's information space with relation to an individual's information activities and contexts like time and people. Crucially, current research stands at a threshold, seeking to understand and bridge these areas together to create *integrated digital work environments*, as explored in (Kaptelinin and Czerwinski, 2007). This integration emphasises the unification of data (Karger, 2007) that users access through their devices to overcome the *information fragmentation* (Jones *et al.*, 2005) that occurs across tools, devices and contexts.

Today, the user's electronic information space consists of various discrete partially structured collections of items, scattered across various personal devices, web sites and web services, locations of use, activities and time. Recent developments seek to offer tighter integration with centralised services (e.g. Google online and device-based services and Microsoft's Live Mesh). At present, however, there is no integrated way for users to view and access the entirety of their distributed, evolving, personal information space, in a richly visual, personalised and associative way that matches their work context.

This research investigates and develops the idea of a Pervasive Personal Information Space. The concept integrates information across devices and employs a variety of presentation and interaction styles for anytime-anywhere access to a user's personal, distributed electronic information. The emphasis is on designing a personalised computing experience by tailoring the information interaction to the user; designing information according to the unique characteristics and contents of the user's information space; and organising, visualising and accessing information according to the user's physical, social, temporal, information, device and activity contexts.

The research work seeks to extend the accumulated knowledge and understanding in HCI with respect to supporting everyday user information activities within the ubiquitous/pervasive computing environment. The research was carried out alongside the recent and continuing work on systems like Haystack (Huynh *et al.*, 2002), MyLifeBits (Gemmell *et al.*, 2002) and Chandler (OSAF, 2003). These developments have varying goals, but they all take a more user-centred view, seeking to adapt information organisation, presentation and access to the user's needs. The primary contribution of this thesis is in providing explanatory and generative theories on developing Pervasive Information Spaces for different user domains, and specifically for the domain of personal information spaces.

1.2 RESEARCH QUESTIONS AND HYPOTHESIS

The objective of this research work was to develop and implement a model for Pervasive Personal Information Spaces that helps individuals manage, visualise and access information in their ubiquitous computing environment. Accordingly, the research aimed to answer the following research question and sub-questions.

Research question: How can we integrate, personalise and contextualise information to provide effective support for ubiquitous access to personal information spaces?

Sub-questions:

- How can high-level user information activities be supported in a ubiquitous computing environment?
- How can the presentation of and interaction with the user's information space be modelled to match the user's entire use context?
- How can personal information spaces across multiple devices be integrated to support better contextual access and visualisation of information?
- How can the user's work or activity context be presented and preserved across devices and locations?

These questions directed the main ideas explored in the research, which include:

- Tracking and presenting user information as part of their high-level activities.
- Bringing together activity, information, social, physical, temporal and device contexts of use in the views of the information space to better reflect the user's work context.
- Generating *flexible views* for accessing and visualising information that are tailored to user activity, work context and device capabilities, to support the changing information-interaction in the ubiquitous computing environment.
- Creating an integrated repository of information across an individual's devices, with detailed information relationships to support activity work, information archiving, synchronisation and information adaptation to device and context in ubiquitous computing.
- Automating information monitoring and synchronisation on all of an individual's personal devices to preserve work and activity context with minimum user effort.

These ideas form the basis for a comprehensive model, which were partially implemented as the InfoMesh system, to investigate and evaluate its support of anytime, anywhere and any-context style of personal computing.

The **hypothesis** that InfoMesh was designed to test is as follows:
Context-based flexible views provide better contextual, ubiquitous access and visualisation of information than current single-device metaphors.

1.3 RESEARCH METHODOLOGY

The Pervasive Personal Information Spaces concept encompasses a wide and varied theoretical and practical framework, which guided the methodology employed in carrying out the research work. The focus of the methodology was to define, model, implement and investigate the central concept of Pervasive Personal Information Spaces, so that current research could be extended with a practical framework and guidelines for developing these integrated digital environments. The methodology followed several phases of work that were highly iterative due to the broad nature of the research.

The first step in the research was to consider research topics and developments relevant to the idea of Pervasive Personal Information Spaces within Human Computer Interaction and various related fields. Topics of interest focused on the foundational theories, users and information interaction, the ubiquitous computing environment, models and techniques, design and development methodologies, relevant systems and issues raised by the research.

The next step involved exploring, defining and describing the concept of Pervasive Personal Information Spaces, its user domain and research space, with the research literature in mind. The concept was then modelled into a framework, namely the Spaces model, which defined the characteristics that Pervasive Personal Information Spaces would ideally exhibit in the real world. Before implementing a prototype according to this model, the research objectives and scope had to be clearly defined and, on several occasions, revisited and refined. This kept the ongoing research focussed, manageable and within what was technologically and practically feasible. The Spaces model and the research scope formed the basis for formulating functional and non-functional requirements for an implementation of Pervasive Personal Information Spaces.

An iterative interface and interaction design phase followed, exploring a variety of alternative designs. As the research emphasised detailed visualisations and a high level of interaction, a variety of design tools and techniques were used to inform the design phase. These included a focus group study, various personas, scenarios of use, and a tool developed specifically for this research work called *activity snaps*. The interface and interaction designs were accordingly developed and tested using the personas, scenarios of use and activity snaps, and refined

numerous times. Simple interface walk-throughs and heuristic evaluations were also utilised in testing and updating the designs.

The system design and prototyping underwent a similar highly iterative process. The system architecture, object models and application processes were tested and refined according to their effectiveness and appropriateness for the programming environments, as well as their ability to successfully match the goals for the system functionality. The designs were then implemented as the InfoMesh system. The prototyping process took into account multiple devices (desktops, laptops and PDAs), technological limitations and feasibility, and limitations of specific programming environments. Various structural and functional tests aided in checking functionality, communication and integration in InfoMesh, and subsequently, in updating and adjusting the underlying requirements and design, and the tools used to implement the Spaces model.

User-based evaluation of InfoMesh occurred in various stages, which studied the visualisations, interaction, and potential long-term use of the prototype system in several studies. Techniques employed varied with the type of user study conducted, and included questionnaires, discussions, scenarios, activity snaps, prototype demos and tutorials, paper prototypes and functional prototypes, exploratory tasks, assessment tasks, comparison tasks, and remote evaluation methods. Findings from these studies helped assess the Spaces model and the concept of Pervasive Personal Information Spaces, improve InfoMesh design and usability, and test the research hypothesis.

The conceptualisation of Pervasive Personal Information Spaces, the Spaces model and the InfoMesh development process then finally helped formulate guidelines for developing Pervasive Information Spaces for a variety of user domains.

1.4 CONTRIBUTIONS OF THE THESIS

The thesis makes a variety of contributions to the research areas in HCI relating to ubiquitous computing and access to distributed information; information design, contexts and visualisation; as well as the process used for prototyping interactive systems. These contributions deal directly with answering the research questions,

extending the knowledge within the research area, as well as providing new tools and techniques:

- A review and synthesis of related research, which also identifies some of the limitations in prior work.
- An understanding of *contexts within personal information interaction*, focussing on high-level activity, information, temporal, physical, social, device and goal contexts, along with their characteristics, information relationships and bearing on computer-supported user activity.
- The *Spaces model*, a conceptual framework for developing Pervasive Personal Information Spaces, that emphasises information integration, automation and communication, and flexible views.
- The concept of *flexible views* for contextual information visualisation and retrieval that allows users to match views of their information space to the different dimensions of their work context. Flexible views incorporate user activities and other contextual details in representing and providing access to distributed information.
- A mapped out design space for Pervasive Personal Information Spaces, which considers a variety of information elements and graphical presentation techniques for creating flexible views. The interface, interaction and information designs for the InfoMesh system provide many of these detailed insights into the design space.
- The *activity snaps* tool for use alongside personas and scenarios in the process of conceptualising, designing, prototyping and evaluating interactive systems, especially where these systems emphasise visualisations and real-world user activities. Use of activity snaps is outlined through the PSA life cycle (personas, scenarios and activity snaps life cycle).
- A method of employing semi-automated processes for querying, monitoring, registering, integrating, presenting and synchronising information on all of the user's devices to minimise user effort in managing and accessing information.
- A *Composer-Worker-Presenter* architecture for translating the Spaces model into a system design and implementation. The architecture also supports a detailed information design for use with Pervasive Personal Information Spaces, which brings together information item attributes emphasising

contexts, relationships, item representations, annotations, and workspace and action markers.

- The *InfoMesh* prototype system for desktops, laptops and PDAs, which helped in testing the research hypothesis and which serves as an example implementation of Pervasive Information Spaces for the selected user domain of distributed personal information spaces. InfoMesh furthermore lends itself as an illustrative case study for the use of activity snaps in the analysis, design, prototyping and evaluation process.
- Details of everyday user information-interaction in the ubiquitous computing environment, user views on the ideas underlying Pervasive Personal Information Spaces, and subsequent views on user ubiquitous information-interaction needs, as uncovered through InfoMesh evaluation.
- Guidelines for developing Pervasive Information Spaces for different user domains and information collections.

1.5 THESIS OUTLINE

Chapter 2 describes the research background for the research, focussing on frameworks and theories, users and information, the ubiquitous computing scene, information organisation and presentation, relevant issues and related systems, as well as the limitations of previous work that this thesis aims to address.

Chapter 3 explains the concept of Pervasive Personal Information Spaces, emphasising personal information spaces, user activities, and user work contexts. This conceptualisation forms the basis for the Spaces model, a framework for delineating and developing the ideas underlying Pervasive Personal Information Spaces. The chapter then lists the functional and non-functional requirements formulated for an implementation of the Spaces model.

Chapter 4 first presents the designs that form the basis for the interface and interaction of the implemented system. The chapter also describes the tools that supported the design phase, namely personas, scenarios and the newly developed activity snaps.

Chapter 5 describes the InfoMesh prototype system and discusses how users can view and interact with the information space using InfoMesh, with specific scenarios and activity snaps worked out for the persona 'Aran'. The chapter then

describes the system architecture, system environment, and the prototyping process.

Chapter 6 first describes the background approach taken in evaluating InfoMesh in this research. Evaluation occurred in several phases, and chapter 6 reports on the first phase of user evaluation focussing on InfoMesh visualisations, with methodology details, an analysis and discussion of findings, and the implications of the study on further InfoMesh development.

Chapter 7 reports on the second phase of user evaluation focussing on InfoMesh visualisation, interaction and use, and reflects on the future long-term evaluation of InfoMesh. Once again, the study is presented with methodology details, an analysis and discussion of the findings, and the study implications. A final discussion subsequently summarises the key findings from all the studies and their support for the research hypothesis.

Chapter 8 concludes the thesis work, by first presenting and discussing guidelines for developing Pervasive Information Spaces. The chapter then summarises the research work and the contributions made, and describes the direction of envisioned future research.

CHAPTER 2 - BACKGROUND

PERSONAL INFORMATION INTERACTION IN THE DIGITAL WORLD

2.1 INTRODUCTION

Successfully developing and implementing Pervasive Personal Information Spaces involves an understanding of a variety of subject areas. This chapter reviews research of interest to the work on Pervasive Personal Information Spaces, focussing on:

- Frameworks, theories and paradigms suited to human-computer interaction design for supporting user information interaction in an ubiquitous / pervasive computing environment.
- The central theme of users and information, emphasising user characteristics and psychology, human-information interaction behaviour, and daily user information activities.
- The ubiquitous and pervasive computing scene, focusing on systems and architectures in use and in development in this area, characteristics and use of computing devices and communication technologies, and evaluation techniques for ubiquitous applications.
- Models of information organisation, and techniques for information presentation and interaction.
- Issues of privacy, security, social concerns, and universal accessibility with relation to collection, access and control of information in an ubiquitous and pervasive computing environment.
- Relevant information management and knowledge access systems for personal and ubiquitous use.

These topics provide a context for the research, support and inform the underlying ideas, and help develop the research concept. The chapter concludes by explaining the limitations in previous research developments that Pervasive Personal Information Spaces seek to address.

2.2 FRAMEWORKS, THEORIES AND PARADIGMS

Several theories and paradigms provide a strong framework for supporting user interaction with electronic information, by taking into account the user's activity, the physical and social context of their activity, their continuous knowledge acquisition and application, and their distributed, changing information space.

They play an important role in the design and development of Pervasive Personal Information Spaces.

2.2.1 EVERYDAY COMPUTING

The theme of *Everyday Computing*, detailed by Abowd and Mynatt (2000), considers scaling interaction with respect to time within the ubiquitous computing environment, alongside scaling with respect to devices, physical spaces and people. The authors explain the need to support the informal, daily activities of individuals with the idea of continuously available, integrative and unobtrusive interaction, as computing becomes a constant presence.

People's activities do not always have a clear beginning or end, they are often interrupted and performed alongside other activities. Abowd and Mynatt explain that time is an important discriminator in finding and interpreting details of these activities, as the activity context continually changes. They argue that activities are best supported by associative models of information, as they can provide multiple perspectives on an information space according to the activity context.

Two challenges offered by everyday computing include the design of a computer interface that is continuously present and the integration of people's activities in the physical and virtual worlds (Abowd and Mynatt, 2000).

2.2.2 ACTIVITY THEORY

Adapted to HCI, *Activity Theory* can be used as a framework for understanding the structure, development and context of computer-supported activities (Kaptelinin and Nardi, 1997). Activity theory focuses on people's activity context and experience. Hypponen (1998) states that within this framework, users can be seen as active agents in their own life and development. The basic principles of the theory are as follows (see Hypponen, 1998, Kaptelinin, 2000, Kaptelinin and Nardi, 1997):

- Hierarchical structure of activity: Activity is motive driven and directed at an object, and consists of goal driven actions and opportunity-driven operations.
- Object-relatedness: The reality where activity takes place is objective. Objects have properties defined scientifically, socially and culturally.

- Internalisation/externalisation: Activities can be internal (mental processes) or external (external behaviour). Internal and external activities transform into each other in the processes of internalisation and externalisation.
- Mediation: Individual and social activities are mediated by language and technology, through which social knowledge is accumulated and transmitted. People are shaped by individual and group activities.
- Development: Human activities undergo developmental changes over time.

With activity theory as a framework, Gay and Hembrooke (2003) argue for *Activity-Centred Design (Context-Based Design)* as a model for HCI design that moves beyond user-centred design to incorporate, not only user needs and goals, but importantly the activities and contexts of technology use. Bridging theory and practice, Volda *et al.* (2007) list several aspects of activities that form challenges for incorporating activities in computing. They highlight the multi-faceted, dynamic, collaborative, granular and translocational nature of activities, and explain that activities exist at different levels of granularity and across places. Volda *et al.* feel that activity theory can help define user activities for designing activity-centred applications for the ubiquitous computing environment.

2.2.3 FRAMEWORK FOR DEVELOPING PERSONAL INFORMATION APPLIANCES

Thomas *et al.* (1995) provide *a framework for developing personal information appliances* that focuses on personal devices and their integration with each other, with the user's environment and with the user's information management practices. The framework is based on four main factors:

- Personal information management practices: These include storage of information, retrieval of local and external information, integration of information resources, decision-making, and communication with other individuals and devices, which a personal information appliance needs to support.
- User experience of personal information appliances: Here, the focus lies on supporting transparency, and providing task-appropriate information, customisable user interfaces and support for multi-modal interaction to simplify and enrich human-information interaction.

- Integration of devices and media: This includes support for integration between different application domains as well as different types of information, and integration of appliances into an information environment.
- Enabling technology: These relate to communication and networking, natural interfaces and information engineering technology to support ubiquitous computing and multi-modal interaction, for among others, mobile professionals and knowledge workers.

2.2.4 NAVIGATION OF INFORMATION SPACE

The concept of *Navigation of Information Space* as presented by Benyon (2001) sees individuals as existing in and moving through an information space. Traditionally, HCI design has focused on user interaction with information through the visual interface of a single computing device.

Benyon argues that as the computing environment becomes increasingly ubiquitous and pervasive, with stationary, mobile and embedded devices in constant communication, the individual moves from being outside to being inside an information space. HCI design as a consequence would shift its focus on the creation of this information space around the user. According to Benyon, navigation of this information space can be then simplified by applying styles of semiotics based on real-world navigation.

Benyon further presents the idea of the user's activity space, where all real-world activities take place. These daily activities are affected by the discovery, exchange and management of information. He goes on to state that people are then truly supported when an information space is filled with artifacts that enable and encourage them to understand their activity space.

2.2.5 USER-SUBJECTIVE APPROACH TO PERSONAL INFORMATION MANAGEMENT SYSTEMS

With the *user-subjective approach to PIM systems*, Bergman *et al.* (2003) advocate the need for visualisation and access of information within personal information spaces that is subjective w.r.t. user's information classification, judged importance and context of use. Managing one's personal information is part of the learning process, and they say existing systems often ignore that

personal information management (PIM) systems are organised and used by one person.

The authors explain that general information management (GIM) systems need to rely on objective and general attributes for organisation and retrieval as they cater to many different users. However, as PIM systems serve individuals, their design has to make use of subjective attributes, i.e. attributes that have meaning to the user and are derived from their individual interaction with their information space. The findings of a study by Kwasnik (1991) support this theory and show that users' natural organisation of information heavily depends on subjective attributes as opposed to objective ones.

Bergman *et al.* list three generic principles to their user-subjective approach for the design of PIM systems:

- The subjective classification principle, where information items that are subjectively related to the same topic are grouped together regardless of format.
- The subjective importance principle, where the importance of an information item influences its visibility and accessibility.
- The subjective context principle, where information items can be visualised and retrieved according to the context they were created and used in.

In implementing this approach, the authors recommend finding a balance between an adaptive / automated design and one that rests completely on user control.

Other theories and approaches of interest for Pervasive Personal Information Spaces include Lifelong Learning (Sharples, 2000), metaphors and mental models (Dix *et al.*, 1998, and McDaniel, 2003), situated action (Artman and Wærn, 1995) and distributed cognition (Rogers, 1997).

2.3 USERS AND INFORMATION

Central to this research is an understanding of users and their information interaction. Considering user differences and information behaviour helps develop an interaction model for Pervasive Personal Information Spaces that provides users with different perspectives on their information space and different ways to interact with that information.

2.3.1 USERS

Electronic information is used and managed by the entire diversity of computer users. These users differ in their physical abilities and situations of use, cognitive and perceptual abilities, personality and personal differences, cultural background, and skill and knowledge level (Shneiderman 1997a and 2000).

Vision, hearing, motor, cognitive and neurological disabilities, age-related conditions, and combinations of impairments (Brewer, 2001) can limit access to and interaction with information. This can be overcome to a certain extent by providing a high level of direct accessibility, multi-modal interaction, support for adaptive strategies, and support for personalisation, customisation and automation within the interface. Furthermore, design guidelines for improving accessibility (see Vanderheiden, 1994) also need to be followed.

Within the ubiquitous computing context, situations of use become quite relevant. Users will be interacting with information in different physical locations, at times while mobile. These environments for instance can be noisy, the devices used can differ from place to place, and the user's main activity might require much of his/her attention and interaction. Furthermore, the situation itself can influence what activities are carried out and how.

Cognitive and perceptual abilities of individuals further dictate how information might be organised, presented and navigated. For example, differences in individual learning styles, such as innovative, analytic, common sense and dynamic learning styles (McCarthy, 1987) can affect patterns of work and information exploration, which in turn can affect how information item associations are created. Gwizdka and Chignell (2007) review how individual differences affect information keeping, finding and managing strategies in the digital environment due to the various internal and external factors that influence users. These factors include cognitive abilities, job positions, tool and task characteristics, and information channels and content.

Differences in user intelligences, such as symbol-related, person-related and object-related intelligences (Huitt, 2002) derived from Gardner's multiple intelligences (1983), might be taken advantage of through the use of appropriate, alternative views on information spaces. These views can for example provide abstractions of the underlying information and information relationships,

information arranged around social networks, or real-world style navigable renditions of the information space with meaningful landmarks.

Models of long-term memory (see Huitt, 2003), especially semantic and episodic memory, can be exploited by providing personalised representations of information associations according to time, activity, social contacts and so on.

Other cognitive processes of interest include reasoning, attending, acquiring skills and generating new ideas (Sternberg, 1999, Cahill, 2002). The appropriate collection and presentation of an individual's activity and information behaviour can help support these processes. For this, information representation will need to take into account user's mental models of the information, laws of perceptual organisation and multi-sensory interaction abilities.

Personality, cultural and individual differences (like gender and language preferences), as well as differences in skill and knowledge levels (ranging from first time computer users to programmers and from domain specific novices to expert users (Shneiderman, 2000)) can be supported in part by automation and customisation options. Adaptive systems that take details of the user, usage and contexts of use into account can further support user diversity (Stephanidis, 2001). It is however not enough to only consider users individually. People interact socially and take on many social roles next to individual ones, and share interests and exchange information (Knudtzon, 2002). The groups they form also have characteristics, based on cumulative abilities, work methods, social patterns, and cultural and historical background and developments.

2.3.2 HUMAN-INFORMATION INTERACTION

Human-information interaction encompasses user information behaviour, information management practices and behavioural information activities. User information behaviour and management practices are ongoing processes, and include the process of transforming available information into useful information, organising and managing that information. Behavioural information activities include information foraging, information exploration and sense-making, information retrieval, social navigation, and knowledge work. These reveal important insights into how people collect the information and knowledge they need for any activity and how the information is related back to the activity.

Information transformation process

Users go through a continual process of creating and gathering, filtering and organising, processing, and finally using information as they interact with their personal collections of information (Ackerman, 1996, Steier *et al.*, 1998, Thomas *et al.*, 1995, and Wilson, 2000). The information transformation process effectively depicts stories of user activities, generating a myriad of information associations throughout the process.

Information collection involves authoring information, sharing information, transferring information to electronic form, and retrieving information from different sources according to activities and goals. Collected information items quickly form the basis of other generated and shared information, and emphasise the current activity and information context of the user.

Once information is gathered, users filter and organise the information space to improve retrievability and understandability, which helps in reminding them of their current tasks and tasks still requiring attention (Ackerman, 1996, Malone, 1983, Mander *et al.*, 1992, Whittaker and Hirschberg, 2001).

Users finally analyse and process the information according to their information and activity context, plans and goals, before use. Afterwards, information is frequently passively stored long-term or consciously archived for future reference or use.

Electronic information organisation and management

A number of studies on information organisation and management offer insight into user information management practices for developing Pervasive Personal Information Spaces. These include studies that focus on:

- Information management in the paper world (e.g. Kidd, 1994, Malone, 1983, Mander *et al.* 1992 and Whittaker and Hirschberg, 2001): people pile information according to tasks and dates, with spatial layout and visual cues exposing details of the information space, and they file information as a way to categorise information for future retrieval and create archives.
- A single tool or domain such as email (e.g. Whittaker and Sidner, 1996), web information and references (e.g. Jones *et al.*, 2001) and files (e.g. Barreau and Nardi, 1995, Krishnan, 2003 and Krishnan and Jones, 2005): individuals' use of a variety of tools and strategies, according to the specific function they

offer (e.g. email to self as a reminder, saving a web page to preserve the information, using file naming conventions to identify and relate files to each other), according to individual differences (e.g. never filing information, filing frequently or spring cleaning email), or according to information type (e.g. using location-based browsing for working information and keyword searches for archived information).

- Cross-tool information management practices (Boardman and Sasse, 2004, and Teevan *et al.*, 2004): individuals utilise a variety of organisation, management and retrieval strategies within and across their tools (i.e. email, bookmark and file systems), range from full filers to no-filers, and use orienteering and teleporting approaches according to information organisation and use context, with browsing-based retrieval preferred over keyword searches across all tools.
- Specific modes for information management, organisation and / or retrieval, such as folders and tags in email (Civan *et al.*, 2008) and landmarks in email (Ringel *et al.*, 2003): folders and tags each have their strengths and weaknesses, but do not fully capture user information perceptions, and the use of various landmarks can support faster information retrieval.
- The actual content and organisation of information in individuals' personal document spaces (Gonçalves and Jorge, 2003): the average number of devices per person is about 1.45 not including handheld and secondary devices; users vary between file-rich (up to 25000 files), file-average (under 10000 files) and file-poor (under 1000 files) users according to their occupation and work; about 80% of the information space is inactive; and filenames have an average length of 12.56, but have a very high standard deviation.

Information foraging

Information foraging, as presented by Pirolli and Card (1999), provides a background for understanding how people seek, gather and use information in a complex, changing information environment. There is an understanding that individuals create information structures and develop strategies to maximise the value of the information gained per unit cost. Information foraging covers several main notions (Pirolli, 2001, Pirolli and Card, 1999):

- Information patches: Information clusters that the user seeks information in or moves between. Individuals engage in environment enrichment activities and information scent activities in deciding how to organise information patches and which to visit next.
- Information scent: Active use of local cues to support exploration, navigation and assessment of information spaces.
- Information diets: Selection of information items and sources through scent to maximise the gain of information relevant to the task.

There is also a further social/co-operative and sense-making side to information foraging.

Information exploration and sense-making

Information exploration fits within the activity of information foraging, where individuals look for new information within a select area. Baldonado and Winograd (1997) list the three features of information exploration as follows:

- Gathering a set of information items helps in discovering further items.
- Frequently a variety of heterogeneous sources need to be consulted.
- User interests evolve according to the changing information context.

The changing information context helps individuals make sense of the information space and their own information needs.

Information retrieval

Several important aspects of information retrieval relevant to this research include information orienteering behaviour in both information exploration and information retrieval (O'Day and Jeffries, 1993 and Teevan *et al.*, 2004), retrieving information using a teleporting strategy (Teevan *et al.*, 2004), faceted information searches and navigation (Hearst, 2008), and contextual and associative information retrieval (Chau *et al.*, 2008 and Rothrock *et al.*, 2006). Information orienteering describes a search behaviour where users arrive at a result through a series of steps, using several pieces of remembered details. As these details are often contextual, they cannot be formulated as a direct query. Teevan *et al.* (2004) explained that users may well be comfortable with orienteering behaviour as it seems to reduce their cognitive load, gives them a sense of where they are in their information search, and helps them understand

their search results better. Teleporting strategies (i.e. jumping directly to an item using a keyword search) on the other hand take a user directly to their target, but require more effort in formulating the right query and can be disorienting. Faceted information search allows users to flexibly navigate by information categories, where those categories are essentially labels that information items are tagged with (Hearst, 2008). As items can have multiple labels, faceted searches are not constrained by a strict organisation, and can fluidly adapt and expand on selected categories, supporting information exploration and discovery. Associative or contextual retrieval on the other hand supports searches and navigation based on various information associations that occur naturally in information interaction rather than explicitly assigned labels. In finding personal information, Teevan *et al.* (2007) explain that the person seeking the information, the actual information target as well as the task context influence the retrieval of information.

Social navigation

Social navigation occurs when information about the actions and activities of other users guide and inform a user's action (Dieberger *et al.*, 2000). This information can encompass information traces left by users about their browsing or shopping behaviour, user reviews, recommendations and comments. In the digital information environment these details abound, and individuals use them to navigate through a deluge of information to find sites and items of interest. These details can be directly visible or in an aggregated form and hidden, anonymous or associated with a single person or group of people, but most important of all they are personal and dynamic in nature (Dieberger *et al.*, 2000).

Knowledge work

Knowledge work is mainly cognitive work carried out to generate useful information and knowledge (Davis, 2002). Davis explains that in knowledge work, individuals access data, employ mental models, and build and use knowledge. The work itself requires much concentration and attention. Davis and Naumann (1997) identified three types of knowledge work tasks: job-specific, knowledge building and maintenance, and work management tasks. Basically, individuals have work that is directly related to the information and knowledge they generate as plans, analyses and documentation. At the same time, they try

keeping their knowledge up to date, plan their work and gain access to required resources. Knowledge workers acquire information from different locations, activities and people, and build on their personal knowledge, knowledge from repositories and other knowledge workers. Efficient work flow and work methods, as well as good self-management are of immense significance to the knowledge worker (Davis, 2002).

2.3.3 INFORMATION AND INFORMATION ACTIVITIES

Everyday tasks require individuals to acquire and combine vast amounts of knowledge to for instance define goals, build skills and decide on courses of action (Pirolli and Card, 1999). In their tasks with electronic information, users have to deal with a variety of information types and information resources to do so. Some classifications of information types and collections include:

- Actively (e.g. reports and e-mails) and passively (e.g. web browsing trails) created information, where the user's level of awareness about the information varies.
- Structured, semi-structured and unstructured information, which influence the way items are created, categorised and organised. Some of the unstructured information can actually be *information scraps* as described by Bernstein *et al.* (2008), which in the electronic world can take the form of miscellaneous notes in text files on the desktop or in email.
- Ephemeral, working, archive (retrospective) and prospective information (Barreau and Nardi, 1995, and Gwizdka, 2000), where information items are classified according to frequency of access, task relevance, and period of use (past, present and future).
- Active, dormant, not-useful and un-assessed information (Boardman and Sasse, 2004), where information is classified according to its use or usefulness.
- Multi-media formats of information, text, image, audio and speech, which dictate interaction and presentation modes used to create and access items.
- Real world (personal papers and books, local libraries) and virtual (WWW, digital libraries) information sources, which differ in the kinds of interaction they support.

- Personal, organisational, public / person-less information, where authorship and rights to access and use of information vary. Collections that are specifically personal, organisational or public further have unique goals, characteristics and uses.

Information can further be classified by the kinds of activities users perform using information. Electronic information activities, abstracted in different ways, can include:

- Activities of information gathering and access (e.g. personal and shared information repositories, browsing the web), information generation (e.g. word processing), information retrieval (e.g. querying the web, scanning the information repository), collaboration / co-ordination (e.g. discussing plans for a workshop with an online meeting), communication (e.g. sending e-mail, video conferencing), managing transactions (e.g. shopping, finance) and personal information management (e.g. managing contacts).
- Activities relating to work (e.g. preparing an end-of-the-year report), study (e.g. writing an essay) or leisure (e.g. managing an electronic photo-album).
- General, socially specified categories such as travel (e.g. booking flights online), retail (e.g. browsing and shopping online), health (e.g. participating in health care forums), finance (e.g. managing expense details), professional (e.g. preparing a presentation), education (e.g. writing a research paper), and hobby (e.g. reading an e-zine) (CyberAtlas, 1999-2003).
- User-specified activities, such as ‘personal web site’ (involving creation and management of site pages) and ‘stocks and shares’ (involving management of personal stocks, shares and trading resources and ongoing trading details).

These classifications on information and abstracted information activities provide a variety of information-based perspectives on the user’s context and task, and on the relationships between information items within a context of use that can be used in visualising (or rather perceptualising) the information space.

2.3.4 UNDERSTANDING USER, INFORMATION AND ACTIVITY CONTEXT

Details about the user, their information behaviour, the information they are manipulating, and their information activities help with understanding the

information interaction and use context. This context helps users make sense of their changing needs and behaviour, and supports their matching real-world activities.

According to Abowd and Mynatt (2000), the user's context of use can be constructed from different related context services, according to the "five W's" of context, namely who, what, where, when and why. These details give a context for a user's information interaction and use, as well as an understanding of the different perspectives that can be offered on the information space according to the contextual details of interest in each situation. This is especially the case when the current context of information use progresses from another (Baldonado and Winograd, 1997). The use context can then be used to remind one of a current or past activity and behaviour, and form the basis for learning and exploring. For example, individuals create conceptual anchors (Teevan, 2001), where they remember important contextual details and use these to find information and orient themselves in the information space. Furthermore, users often need to return to a previous context for pursuing different alternatives, as well as to continue their task from that previous context (Baldonado and Winograd, 1997), which is of special importance with anytime-anywhere computing.

2.4 THE UBIQUITOUS AND PERVERSIVE COMPUTING ENVIRONMENT

Pervasive Personal Information Spaces belong in the world of ubiquitous and pervasive computing. The ubiquitous / pervasive computing environment is characterised by a high level of mobile and embedded computing capabilities, potentially allowing users anytime-anywhere access to information and services. With ubiquitous computing, the focus of attention shifts away from computing devices to people and their daily tasks (Weiser, 1993), as devices slowly disappear into the background.

The goal of ubiquitous computing can be seen as providing "*many single-activity interactions that together promote a unified and continuous interaction between humans and computational services*" (Abowd and Mynatt, 2000). As such, human-computer interaction in ubiquitous computing seeks to match real-world human interaction and moves towards implicit input, multiscale and distributed

output, and a smooth integration of the physical and virtual worlds (Abowd and Mynatt, 2002).

Aspects of ubiquitous computing include:

- Multitude of heterogeneous, mobile and embedded devices; smart and sentient spaces; variable networks; and adaptable and versatile software (Schultz, 2002, Banavar and Bernstein, 2002, IBM, 2002, Campbell *et al.*, 2002).
- Natural and continuous interaction, automated capture and access of information, and context-aware computing (Abowd and Mynatt, 2000 and 2002). (Dey (2001) explains that context-aware computing requires capture, interpretation and aggregation of context, for its use in providing information and services that are relevant to the user's task).
- Person-centric and task-driven computing (Dertouzos, 1999, Wang and Garlan, 2000).
- Anytime-anywhere, nomadic and interrupted computing (Schultz, 2002, Davis, 2002).
- Continual buying, selling and exchange of information and services in a continuous Information Marketplace (Dertouzos, 1999).

These aspects emphasise certain characteristics, requirements and challenges for applications designed for the ubiquitous computing environment (Banavar and Bernstein, 2002). Banavar and Bernstein explain the need for ubiquitous applications to support the following:

- Task dynamism: An ability to adapt to the user's changing environment and resulting uncertainties.
- Device heterogeneity and resource constraints: An ability to adapt to changes in the technological capabilities in the user's environment whether devices move with the user, or applications move between devices tracking the user.
- Computing in a social environment: Options to regulate the kind and amount of data collection that occurs and its use, to safeguard user privacy.

Research challenges they identified in developing applications include semantic modelling, building the software infrastructure, developing and configuring applications, and validating the user experience.

2.4.1 COMPUTING DEVICES AND COMMUNICATION TECHNOLOGIES

As applications need to adapt to available devices and technological capabilities of the environment, the characteristics and use of these computing devices and communication technologies need to be known. Ubicomp applications (such as an implementation of Pervasive Personal Information Spaces) can then be designed to adapt to the interface, interaction and communication capabilities of the device and environment, according to the user's activity context and needs.

Computing devices (personal, mobile and wearable computing devices) can in part be characterised by their size and form; processing capabilities; storage; display size and type; input and output options; power sources; communication capabilities; level of mobility; and main uses (Zimmerman, 1999a). These characteristics are continually changing with improvements in technology. (A table was drawn up summarising these attributes for desktop computers, notebooks and laptops, tablet PCs, handhelds and cellular phones early on when embarking on the research and development for Pervasive Personal Information Spaces. These details served as a reference when exploring and designing Pervasive Personal Information Spaces for the specific devices that had preferred focus in the research.)

Secondary devices like storage devices (e.g. pen drives, external hard drives) and appliances (e.g. digital cameras, mp3 players) have little or no processing power, but support for example information creation and archiving. They too are part of the user's devices and play a role in his/her information interaction and information space.

Wearable computing devices are worn and controlled by the user (Mann, 1998). Their main characteristics are that they are portable while operational, support hands-free use, have sensors to collect data from the environment, convey information to the user at all times, and by default are always on and always accessible (Mann, 1998). As they can be designed to support different uses and interaction, their characteristics are variable. However, their level of mobility and close relationship to the user makes them ideal for supporting personalised, everyday human-information interaction.

In the current computing scene, devices can be in different connectivity modes, disconnected, always-on, and intermittently connected (IBM, 2002). Within the

ubiquitous computing environment, devices - while mobile - need to be able to easily make and break connections to capture information from the environment, and communicate and off-load computation with nearby devices in support of the user's activity (Zimmerman, 1999b). Unsurprisingly, wireless networking technology offers the most flexible means of sharing information and resources for ubiquitous computing. According to the mobility and wireless range of devices, wireless technology operation can be divided into fixed, mobile, portable and IR wireless (SearchTechTarget, 2003).

For ubiquitous computing, the most useful application of wireless technology is in the set-up of wireless personal area networks (WPAN). In a WPAN, device connections are centred around an individual. All the user's WPAN-equipped computing and communication devices can interconnect when within the individual's Personal Operating Space (POS) (SearchTechTarget, 2003). This kind of networking allows for spontaneous connections, service discovery and delivery, which is central to ubiquitous computing (Zimmerman, 1999b).

2.4.2 SYSTEMS AND ARCHITECTURES

Ubiquitous computing systems and architectures provide an interaction framework for ubiquitous applications. Many of these systems and architectures work around the three themes identified by Abowd and Mynatt (2000) of continuous interaction, context-aware computing, and automated capture and access.

Systems and architectures of interest to this research include Oxygen, Aura, and Personal Agents and Gadget memories, which seek to address Banavar and Bernstein's previously listed research challenges. Though these research developments do not closely relate to the research on Pervasive Personal Information Spaces, they support other systems related to Pervasive Personal Information Spaces with their architecture and therefore offer points of interest in future development and deployment of Pervasive Personal Information Spaces. A couple of the relevant systems supported by these architectures (such as HayStack and Active Documents) are reviewed later in this chapter.

Oxygen

The goal of the Oxygen project at MIT (MIT Project Oxygen, 2002a to 2002d) is to set up a people-centred pervasive computing environment, which is filled with “anonymous devices” that take on user information personalities and communicate naturally. Two main challenges of the project include the anytime-anywhere accessibility of Oxygen and its adaptability to changes in the environment and the user context.

The Oxygen environment seeks to integrate system and user technologies, and provides its own computational and handheld devices, and networks:

- Enviro21s (E21) are embedded everywhere, and perceive the environment, capturing information and performing all heavy computation.
- Handy21s (H21) are mobile handhelds that support communication and basic computing.
- Dynamic Networks (N21) connect the E21s and H21s and helps with locating people, resources, services.

Alongside this, Oxygen also supports several pervasive computational, communication and perceptual facilities of spoken language; sketching and visual cues; knowledge access; and automation and collaboration.

Aura (Interactive workspaces)

The goal in developing Aura (Garlan *et al.*, 2002 and Sousa and Garlan, 2002) has been to minimise distractions on an individual’s attention by adapting computing to the user’s context and needs. Aura’s pervasive computing environment is built around the two broad concepts of proactivity and self-tuning, whereby requests from higher system layers (from hardware to application layers) are anticipated to smooth interaction and layers adapt themselves according to the demands made on them.

The Aura architecture consists of several components, including:

- Coda, which supports nomadic, disconnectable file access.
- Odyssey, which monitors resources and adapts to application needs.
- Prism, a system layer which captures and manages user intent to support user mobility and to hide resource variations from the user. Prism encompasses a task manager, a context observer and an environment manager to support this.

Aura's interactive workspaces assist with migrating tasks between locations, allowing users to carry on tasks they were previously working on elsewhere. At present, Aura provides several context-aware applications (e.g. Portable Help Desk and Handy Andy), and contextual information services (e.g. information on people, devices and physical spaces).

Gadget memory and Personal agents

Gustaffson and Jonsson (1999) put forward an information infrastructure based on the idea of Local Facts and Personal Facts, which can provide context-sensitive information in the highly device-populated computing environment of tomorrow. He explains that these local and personal details support the information-interaction reality, where individuals are continuously moving between personal (personal devices, data and services), public-local (direct local environment) and public-global (Internet, and information without local or personal references) information domains.

Within this infrastructure, Gadget Memories in the direct environment act as information repositories for local facts. An individual's devices can quietly collect relevant information from the local repositories for later use. In a similar way, Personal Agents act as a repository for personal facts, which are (continuously) collected and passed on to different services, such as the Active Documents service. This service is able to present documents as the user needs them, while the user moves through a heterogeneous computing environment.

2.4.3 EVALUATION

Ubiquitous computing takes human-computer interaction outside of home and office alone, to where the individual moves within a continually changing, heterogeneous computing environment, interacting with a variety of different devices, surrounded by an Information Marketplace (Dertouzos, 1999). Not surprisingly, evaluations of ubiquitous applications in a traditional lab environment can no longer suffice.

Abowd and Mynatt (2000) suggest that, while developing ubiquitous applications according to how it might serve a human need, we can only evaluate them by observing and studying their real-world use. They explain that the process starts off with generating a compelling scenario of the human need the application will

serve, which is built around the activities that the designer is him-/herself exposed to. The evaluation itself has to then be conducted from an informed, user-centric perspective in the context of authentic use, focusing on how individuals use the system, what activities they engage in, and what their reactions are.

Users' tasks, context and behavioural patterns in ubiquitous computing will change to fit their new freedom (Jessup and Robey, 2002). Traditional task-centric evaluation techniques might therefore not always be sufficient or appropriate. In this setting, Consolvo and Walker's (2003) application of the Experience Sampling Method to evaluate ubicomp applications shows promise. The method of 'time sampling' and 'momentary assessment' involves participants filling out brief questionnaires several times daily in response to alerts. The questions deal with user activities and feelings of the moment and are not place bound. As a consequence, this method can help in understanding user movement through the ubiquitous computing information space, their social interaction, and interaction with information sources and devices.

2.5 MODELS AND TECHNIQUES FOR INFORMATION ORGANISATION, PRESENTATION AND INTERACTION

A Pervasive Personal Information Space encompasses all of a single user's distributed information space. Anytime-anywhere computing through that space requires an appropriate model for organising, presenting and interacting with the underlying information.

2.5.1 INFORMATION ORGANISATION

People organise their information to minimise the cost of locating and retrieving items of relevance to their information-based work processes (Card et al, 1991).

A first set of models for organising information focuses on relating information items back to the activity, social and location/time context of the user. An *activity-based* organisation relates all information items directly to their use and use context. The task oriented ROOMS system (Card and Henderson, 1987, Henderson and Card, 1986) for example shows how this model supports task switching and reminding. Organisations based around *social networks*, such as Contact Map (Nardi et al, 2002), help link information back to people, facilitating

communication, collaboration and information exchange. Finally, *location* or *time-based* organisation of information helps relate information items back to real world events and places of information use.

A second set of models focuses on abstracting the relationships between the items in the information space itself. These models take on the following representational forms (Shneiderman, 1996):

- *Spatial*: Organisation of information in linear, 2D or 3D space, where location, proximity and arrangement show the relationships between items, as seen with icon arrangements on the desktop.
- *Hierarchical*: Organisation of information in categories and sub-categories, where information items are closely related to items within the same category and parent categories, e.g. electronic hierarchical file systems.
- *Network*: Organisation of items by their explicit relationships, where items are linked to all directly related items, e.g. the World Wide Web.
- *Temporal*: Organisation of items according to time, where relationships between items created, accessed and/or used around the same time become apparent, as seen with web browser history facilities.

These models can be combined selectively to organise an information space according to the nature and use of the information and the associations between the items within that information space.

2.5.2 INFORMATION PRESENTATION

Information presentation techniques assist with identifying items in the information space and deriving meaning from vast amounts of information. Characteristics of information items can be specified through their visual and auditory presentation (e.g. shape, colour, pitch, visual or auditory icons). Their relationships to each other can be presented through arrangements in the visual or auditory landscape (e.g. clustering, 3D sound locations).

Shneiderman (1996) presents several categories of interactive presentation techniques that further support exploration, navigation and access of information:

- *Overview*: Providing a view of the entire collection using aggregation, abstraction and/or selective omission of information.

- *Pan and Zoom*: Supporting navigation by integrating pan and zoom operations, which gives users an integrated notion of large spaces and structures (Furnas and Bederson, 1995).
- *Focus+context and distortion*: Providing a detailed view of a single area of the information space, while retaining contextual information.
- *Detail-on-demand*: Allowing users quick access to information of interest within the representation.
- *Filter*: Allowing users to filter out unwanted information from the information space.
- *Relate*: Indicating relationships among items in the information space.
- *History*: Recording user action and behaviour history to support replay.

2.5.3 INTERACTION

User interaction with their electronic information space can be simplified or improved using a number of techniques, some of which are described below.

Direct manipulation (Shneiderman, 1997b) allows users to see the objects and their actions on the objects in a clear visual representation, which is abstracted from the users' real-world expectations of the objects and actions (e.g. WIMP - windows, icons, menus, pointers style of interaction). Operations on the objects are incremental, immediately apparent on the interface and reversible. Direct manipulation provides interface interaction that is predictable and controllable.

Adaptive techniques allow systems to adapt according to various requirements, born of for example differences in users and task domains. This adaptation can be user-specified (e.g. through options for customising interface presentation and interaction characteristics) or automatic (e.g. through intelligent user interfaces that monitor interaction and adapt according to models of the user, tasks and media) (Stephanidis, 2001). Adaptive techniques can support various levels of *customisation* and *personalisation*, and potentially as a result, universal access. Customisation and personalisation capabilities assist with providing personalised access to information, matching interface presentation and interaction to user work goals, and altering the system to support individual differences and maintaining identity (Blom, 2000).

The automation in adaptive/intelligent user interfaces can further be supported by employing *autonomous agents*. Agents act as assistants that gradually learn more about the user's tasks, interests, habits and preferences, and support an indirect form of interaction (Maes, 1994). Agents can be used to reduce task complexity, perform tasks for the user, monitor activity, guide and teach users, help individuals collaborate and support a more natural interaction environment (Maes, 1994, Maybury, 1999).

Use of *multi-modal / multi-sensory input and output* from a system allows users to interact with the information through a variety of modes (e.g. sight, sound, gesture or touch) (Dix et al, 1998) supporting a more natural interaction. As such, multi-modal design supports access to and 'perceptualisation' of information to support different user abilities, contexts of use, device capabilities, and information types and tasks. Currently, multi-modal design can include the use of speech input and output, auditory icons and earcons; gestural input; input through handwriting; and text, hypertext, and hypermedia (Dix et al, 1998).

2.6 PRIVACY, SECURITY AND SOCIAL ISSUES

The concept of a Pervasive Personal Information Space brings up a number of issues, which relate to the personal nature of many types of information on user devices, and access to and control of this information. Though these issues are not investigated closely in this research, they provide valuable insight for the set-up and management of Pervasive Personal Information Spaces in the real world.

In pervasive and ubiquitous computing, user location and other contextual information can be exploited to provide a better integration of computing into everyday life. This information is collected from the user's environment and behaviour, stored on different devices and transmitted over networks (Abowd and Mynatt, 2000). In the ubiquitous computing environment, the physical and digital world meld together, exposing new vulnerabilities as people accumulate and share information (Campbell *et al.*, 2002). Research into issues raised by ubiquitous computing and the support for privacy and security in this environment has however been limited so far (Langheinrich, 2001).

The concept of a Pervasive Personal Information Space brings many of these issues to the fore, as individual characteristics, information behaviour and context

of the users need to be tracked alongside their actively and passively created information to support a complete and continuous representation of the user's information space. These actions increase the personal relevance and value of Pervasive Personal Information Spaces. As details are communicated between all of the devices the user works with, as segments of the personal information space representation and content are shared in their entirety and so on, issues of privacy and security become very pertinent.

2.6.1 ISSUES IN UBIQUITOUS COMPUTING

Abowd and Mynatt (2000) list four main issues directly related to the design and implementation of ubiquitous computing technology and applications:

- Privacy: Users need to be able to control access and modification of their personal and presence data (Boyd *et al.*, 2002).
- Security: Information needs to be stored and transmitted securely. Data integrity should be maintained. Security options need to be flexible, adaptable, customisable, transparent and secure (Campbell *et al.*, 2002).
- Visibility: Users need to be kept aware of what the systems are doing, what and when information is being collected, and who has access to that information.
- Control: There needs to be acceptable control of the capture, distribution and use of information collected about individuals.

Alongside these issues, there are a wide range of individual, social and cultural issues and concerns with the advent of ubiquitous computing, including:

- Identity issues: A concern individuals might have is to what extent their identity or 'perceived' identity can be exposed through aggregated data collected on them over time and context (Boyd *et al.*, 2002).
- Changing individual, social and organisational behaviour: The proliferation of computing technology into organisational and social settings can result in people rethinking and changing their behavioural patterns (Jessup and Robey, 2002). For example, with anytime-anywhere computing the distinction between work and free time starts to blur, with consequences to the ways individuals and organisations manage these changes.

- **Universal accessibility:** Rapid advancements in technology threaten to leave more and more individuals behind. With these advancements, it is vital that computing technology is designed to provide all the diverse individuals and groups of individuals within the ubicomp environment and the growing Information Society with relatively problem-free access to that technology (Stephanidis, 2001).
- **Omnipresence of technology:** People can be under near-constant observation within the pervasive computing future (Langheinrich, 2001), which can infringe on feelings of having privacy and peace.
- **Legal issues:** Laws and regulations to manage the consequences of technological developments in computer science lag behind the actual advancements. As such, there will be concerns as to how information collected about individuals within the ubiquitous computing environment might be used against them.

As the use of ubiquitous technologies increases, however, more issues will become apparent as individuals' behaviour and use of these technologies change (Abowd and Mynatt, 2000).

2.6.2 GUIDING DESIGN

Working from the fair information practices that the European Directive includes and enhances, Langheinrich provides several areas of focus for regulating privacy and security within the ubiquitous computing environment (2001). He describes the following principles:

- **Notice:** Individuals have to be given notice of the data collected from them. This can include the data collected, the purpose of the collection, the recipients of the data, and their retention.
- **Choice and consent:** Data cannot be collected unless individuals give explicit consent for the collection.
- **Anonymity and pseudonymity:** Users have to be given options to remain unidentifiable, or be identified solely by a pseudonym such as an ID that supports some authentication and personalisation.
- **Proximity and locality:** These stand for the notion of data being tied to the people and places collecting the data. This means, for example, that personal

devices can only collect information when their owner is present and that information collected in a particular location can only be accessed at that location and not transmitted elsewhere.

- Adequate security: Technology needs to support authentic and trusted communication, storage, and computation.
- Access and resources: Technology also needs to support legal requirements of data use limitation, access and repudiation.

Lederer *et al.* present the Situational Faces metaphor in their conceptual model for managing everyday privacy (2002). In this model, users can select a face (an abstracted combination of privacy preferences) that is suited to a situation that they enter into. The authors detail that choosing a pre-created set of privacy preferences to suit the situation helps fight the flood of notice and consent events users will otherwise be bombarded with in ubiquitous computing.

Adapted to Pervasive Personal Information Spaces for example, privacy preferences could be pre-set and abstracted in the same way, according to social roles or identities (see Philips, 2002) and private identities, to match different parts of the information space (e.g. shared information space segments) or support different information behaviour (e.g. on-line browsing and shopping).

Design of ubiquitous computing technology further has to consider design for universal access by considering the diversity of the target users, their individual and cultural differences; the nature of the tasks that are performed using the technology; and the technological platforms and their effect on society and organisations (Stephanidis, 2001).

2.7 RELATED SYSTEMS FOR INFORMATION MANAGEMENT AND KNOWLEDGE ACCESS

There are a number of systems that are relevant to work on Pervasive Personal Information Spaces. These include systems for managing personal information spaces on personal and distributed devices, and those that assist with knowledge access within the pervasive computing context.

2.7.1 INFORMATION MANAGEMENT ON PERSONAL DEVICES

Research into the visualisation and management of personal information spaces has seen various important and interesting developments. This section briefly describes the Information Visualizer, TimeSpace, TimeSpace, Navique, Chandler, Presto and MyLifeBits systems.

The *Information Visualizer* (Card *et al.*, 1991, Robertson *et al.*, 1991) is set up as a workspace for information access, with the goal of minimising the information cost structure. The system uses a set-up of three-dimensional rooms and implements a variety of visualisation techniques and tools, such as Cone Trees, the Perspective Wall and InfoGrid, for abstracting information in the information workspace. The Information Visualizer further provides several agents that help users by assuming part of the workload.

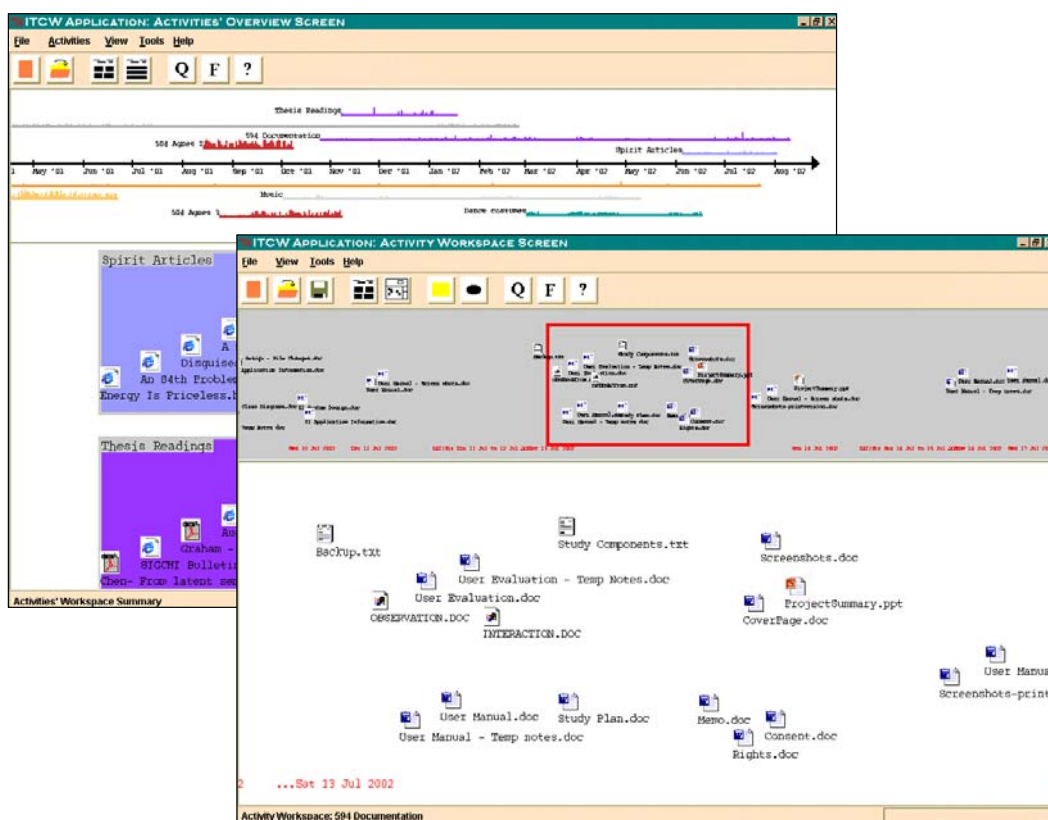


Figure 2-1: TimeSpace, overview and temporal workspace visualisations (Krishnan, 2003)

TimeSpace (Rekimoto, 1999) provides an alternative way of storing and managing documents that takes a time-centric approach as opposed to a hierarchical view such as the folder system. Documents are created and organised on a desktop that moves through different states with time. Items are stored according to creation

time and can be retrieved by travelling back through these states of the desktop. TimeScape provides textual timeline and calendar views, as well as search features to support orientation and navigation.

TimeSpace (Krishnan, 2003 and Krishnan and Jones, 2005) focuses on information visualisation and access according to user activities and time (see Figure 2-1). The system provides an alternative and complementary perspective to the existing hierarchical views of electronic information on desktops and laptops. Items of information are tracked automatically according to user activities and presented in spatial-chronological visualisations. TimeSpace also provides a timeline overview of user activities to help users see and interpret the evolution of their computer-supported work.

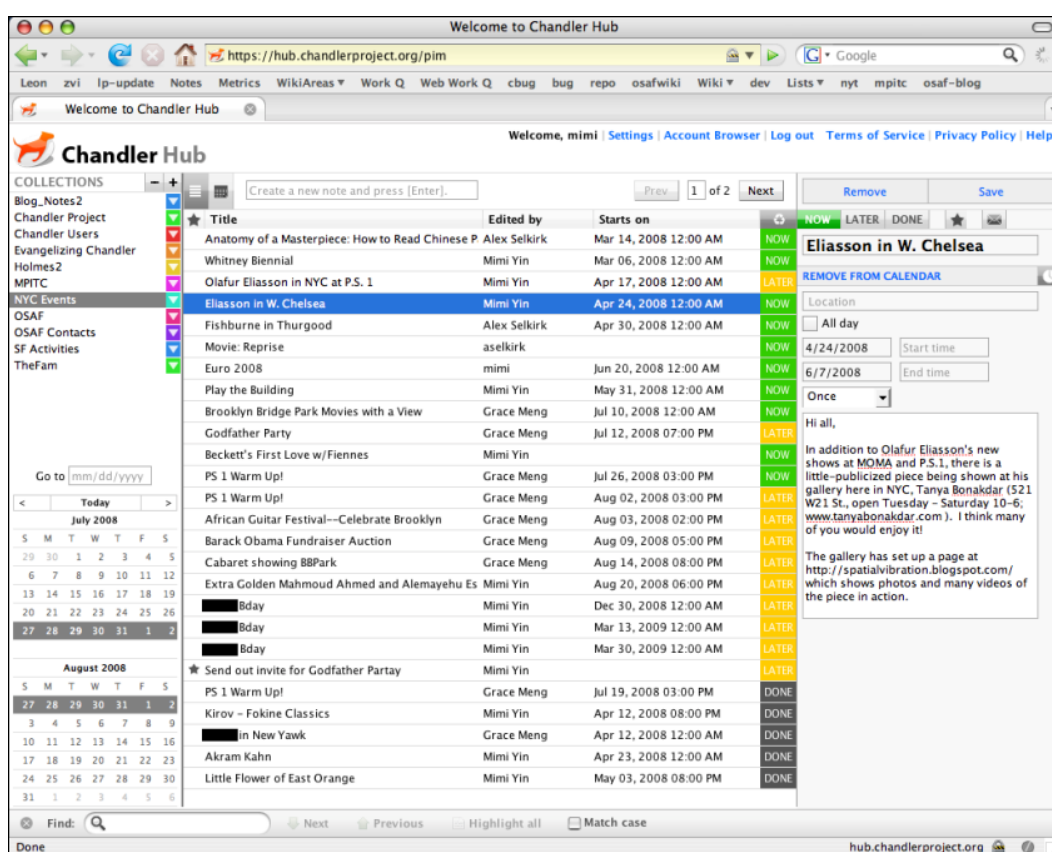


Figure 2-2: Chandler welcome screen screenshot taken from (http://chandlerproject.org/pub/Projects/ScreenShots/web_triagelist.png, 2008)

Navique (Furnas and Rauch, 1998) sets up an integrated information environment that presents the user's personal information space and relevant, external collections of information within a large, virtual workspace representation. The system's goal is to facilitate organisation, navigation and querying of large, personal information collections. To do this, Navique present's the user's current

work, individual and collections of information items, as well as query result sets as information objects on its workspace that can be navigated using pan/zoom capabilities, and where everything (including previous query result sets) can be queried.

Chandler's (OSAF, 2003 and Yin, 2008) focus is on supporting personal information management of e-mail, calendar, contacts and tasks, alongside general information management. Chandler takes a user-centric view and seeks to help users associate and interconnect information items, and gather related items in a single ad-hoc collection that provides a context-sensitive view (see Figure 2-2). Special features of the system include ideas for storing Chandler data on personal and shared devices, tracking multiple concurrent activities, and providing a unified search facility.

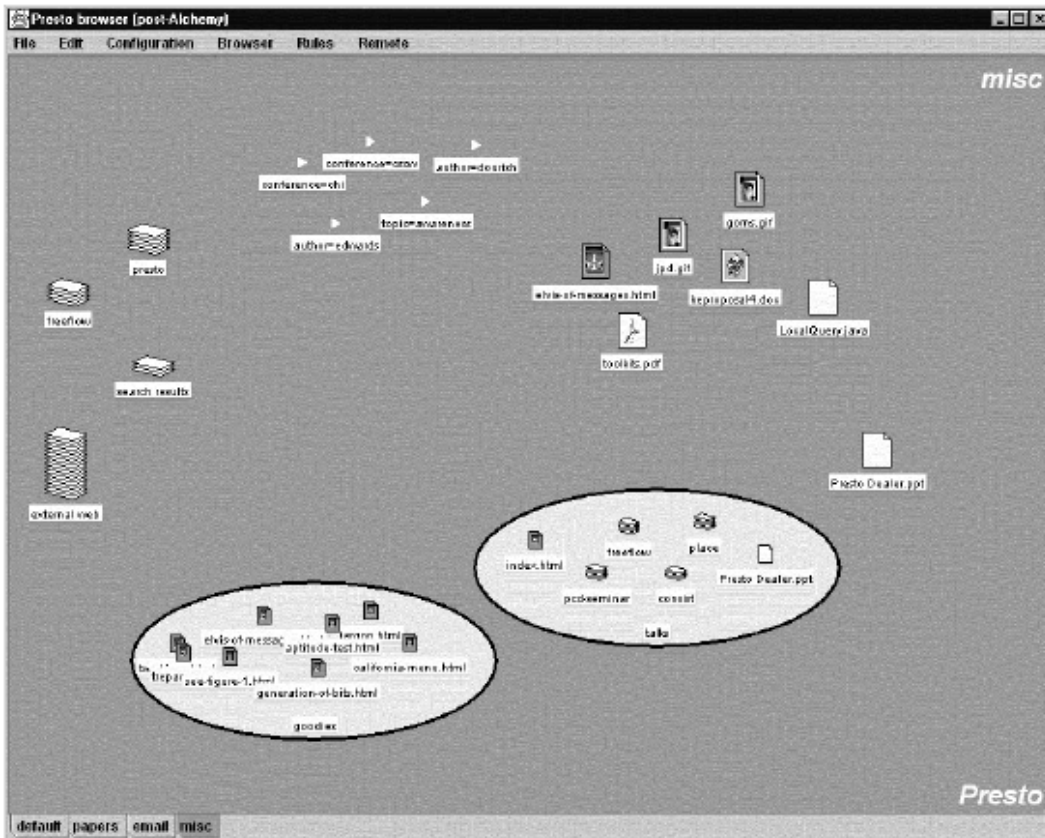


Figure 2-3: Vista, a Presto browser taken from (Dourish *et al.*, 1999)

In the *Placeless Documents / Presto* (Dourish *et al.* 1999 and 2000) system, users are able to annotate their documents with multiple attributes (such as ‘in progress’ and ‘shared with Tony’) to create fluid collections. These annotations form the basis of individuals’ interaction with Presto’s document space representation, i.e. information items are organised, controlled and retrieved according to their

attributes (see Figure 2-3 for a screenshot of the Presto browser). As attributes have meaning to users, the document space structure is strongly connected to the user's immediate concerns and tasks.

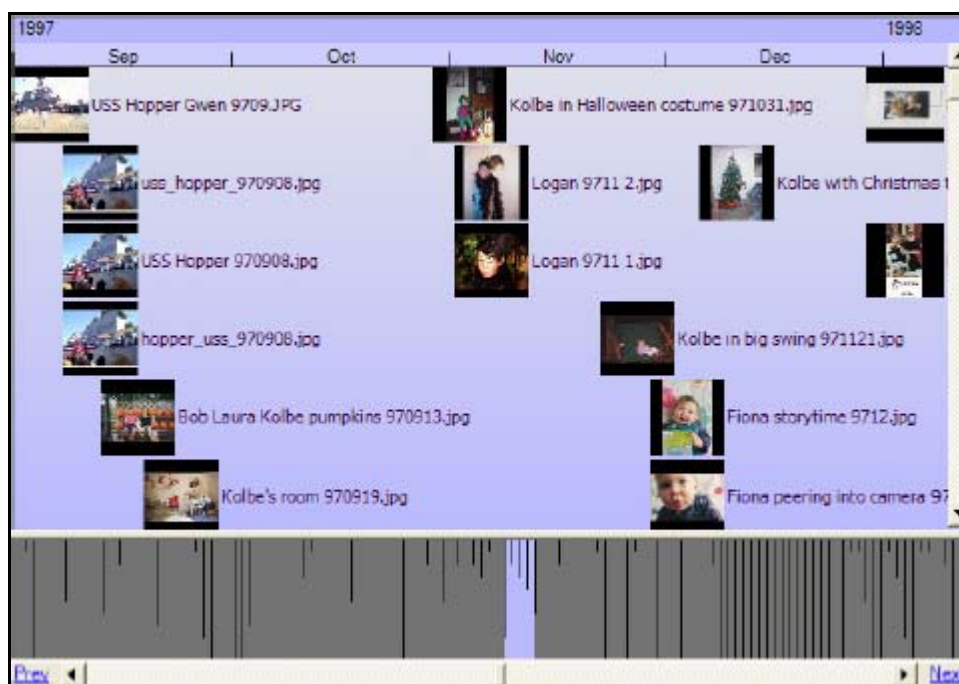


Figure 2-4: MyLifeBits screenshot of a timeline view of query results (Gemmell *et al.*, 2002)

MyLifeBits (Gemmell *et al.*, 2002) implements a system for storing all of a user's media, aiming to replace hierarchical organisations with fluid searchable collections similar to Placeless Documents. Media can be annotated in a variety of ways (with time, text and audio for example) and queried using those annotations to support recall. *MyLifeBits* seeks to then support multiple visualisations on the queried media for better understanding and insight of the information. Currently the system provides a few views, most notable the timeline and clustered-time views of query results (see Figure 2-4). The system also supports the creation of user stories from media as slide shows and time sheets, which annotate the underlying information items.

2.7.2 KNOWLEDGE ACCESS IN UBIQUITOUS COMPUTING

In recent years, research has started to focus on issues of knowledge access in ubiquitous computing. Two interesting developments include the Haystack system (part of the Oxygen project) and Active Documents (part of the Gadget Memories and Personal Agents infrastructure). Other developments of interest include recent

work on the Gnowsis and PLUM frameworks, and the Iolite and Feldspar systems.

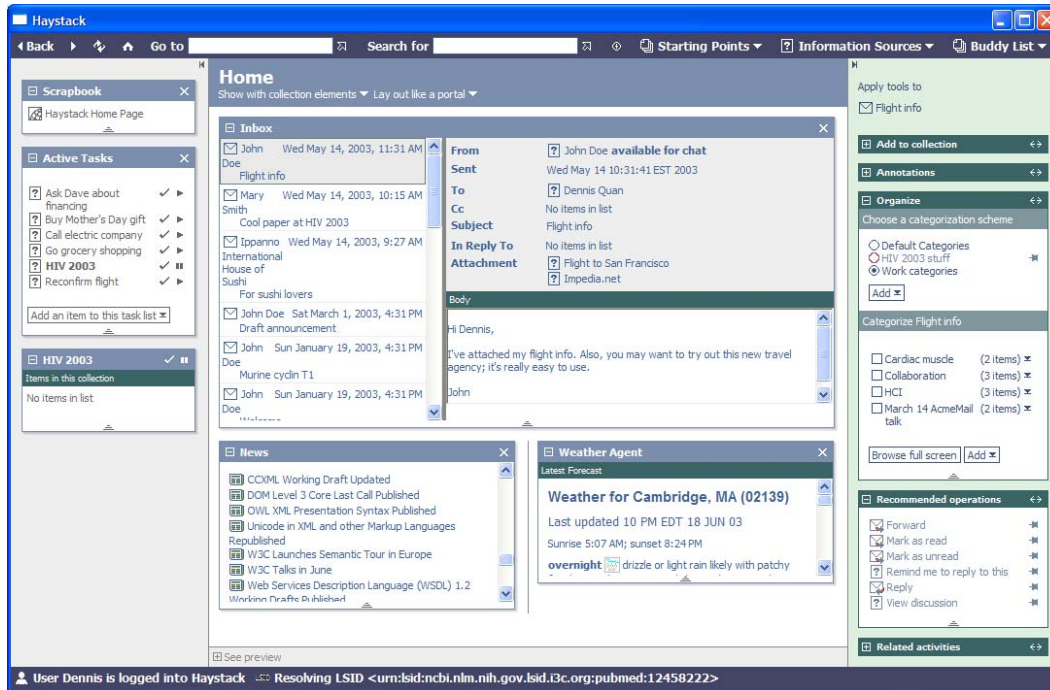


Figure 2-5: Haystack home page taken from (<http://haystack.lcs.mit.edu/screenshots/full-screenshot.png>, 2003)

Haystack (Huynh *et al.*, 2002, Karger *et al.*, 2002) is set up as a tool to allow users to easily manage their documents, e-mail messages, appointments, tasks and other information. The system seeks to support flexibility in describing and organising information; a single homogenous representation of information; easy manipulation and visualisation of information in ways appropriate to the task in hand; and delegation of some of the information processing tasks to agents. Haystack applies a semantic user interface paradigm, where (previously) disparate information is smoothly combined into a presentation. Haystack provides heterogeneous collections of different information (e.g. e-mail, to-do items, documents). Its home page brings together important, directly relevant information to the user, while agents deal with moving things in and out of collections (see Figure 2-5).

More recently, work on Haystack has led to other developments including work on *Gnowsis* (Sauermann, 2008) and *PLUM* (Van Kleek *et al.*, 2007). *Gnowsis*, a semantic desktop environment, can be used to create semantic web and knowledge management applications linking electronic documents across applications on the user's device (such as user emails, documents, addresses and

photos) tagged with annotations. Example applications built on top of Gnowsis include a Personal Semantic Wiki, Thing Editor and Miniquire. Using a framework for representing personal information models (PIMO), these applications aim to link together all the information objects (e.g. documents, people, projects) using conceptual categorisation (Sauermann *et al.*, 2007), which otherwise are largely only related in the user's mind. The goal is to help users file, find and think about personal information. A longitudinal study (cut short by some software issues) showed that participants only made use of specific features and used the applications largely for project and event management, and note keeping (Sauermann and Heim, 2008).

PLUM, a software platform for Personal Lifetime User Modelling, was developed to explore how interaction can be personalised by capturing and modelling a user's behaviour over time (Van Kleek, 2008). The work aims to explore how rich logs of the user's activities and environment can help form the background context for the user, capture personal interaction histories, understand user activity, and interpret the user's situational context to predict his/her information needs. A prototype has been developed so far for capturing user activity and context, along with Jourknow, a note-taking tool to capture user *information scraps* (Bernstein *et al.*, 2008).

Active Documents (Werle 2000, Werle *et al.*, 1999 and Werle *et al.*, 2001) were developed to support users in highly heterogeneous, mobile environments. They are documents that have been turned into mobile agents and are autonomous, reactive, proactive, social, mobile, and adaptable to the current context. Werle explains that active documents are basically aware of their content and aware of the context they are utilised in. These documents can now actively seek out their recipients and transform themselves to suit their role (e.g. shopping list for quick review at the store) and their context of use (e.g. user wants to view the shopping list on a cellular phone).

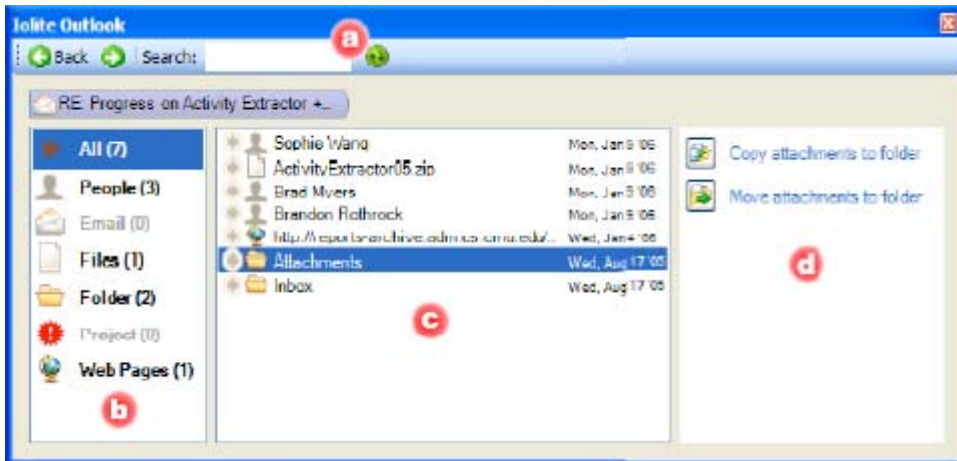


Figure 2-6: Screenshot of Iolite running within Microsoft Outlook (Rothrock *et al.*, 2006)

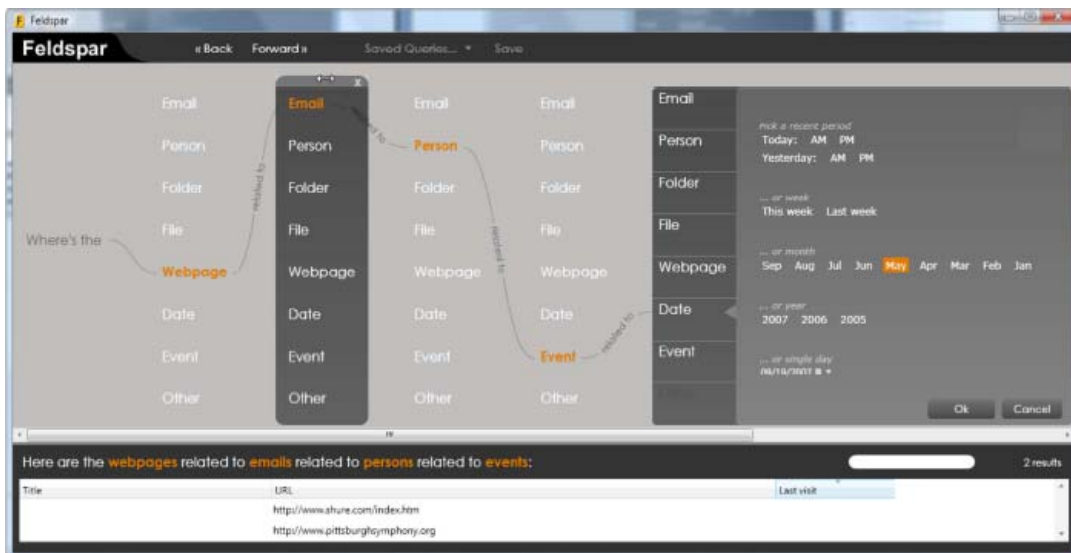


Figure 2-7: Screenshot of Feldspar interface used for file query (Chau *et al.*, 2008)

Two further recent systems are of interest to this research as they focus on associative information retrieval to support information orienteering, as opposed to the teleporting search strategy supported by desktop search applications such as Google Desktop and Apple's Spotlight.

Iolite (Rothrock *et al.*, 2006) helps organise and retrieve information through associations, which are tracked by agents from user interaction and stored in a relational database. Iolite adopts a browser style interface that allows users to select entities and navigate to associated information items (see Figure 2-6 for a screenshot of the interface that shows associations for an email). Currently the system tracks and manages associations for Microsoft Outlook and the operating system.

Iolite made way for work on Feldspar (Chau *et al.*, 2008), which offers a more exciting interface for querying information interactively and incrementally using multiple levels of associations (see Figure 2-7). The interface can help answer associative queries such as “*Find the webpage mentioned in the email from the person who I met in May*” in real time. The system uses Google Desktop functionality to create an information database, index information items, and query the database, and also tracks information associations as a graph. Behind the scenes Google Desktop helps gather details about email, files, folders, web pages, events and dates, after which further associations are extracted for supporting the associative queries.

2.8 ADDRESSING LIMITATIONS OF PREVIOUS RESEARCH

As seen in the last section, research directly related to Pervasive Personal Information Spaces involves work on information space management on personal devices and knowledge access in the ubiquitous computing environment. In these research areas, developments have focused on visualisation and access of information items

- according to tasks/activities and projects, for example ROOMS (Card and Henderson, 1987, Henderson and Card, 1986), Information Visualizer (Card *et al.*, 1991), UMEA (Kaptelinin, 2003), and the Universal Labeler (Jones *et al.*, 2005),
- using subjective information or attributes, such as Placeless Documents (Dourish *et al.*, 1999 and 2000),
- using contextual or associative information, such as MyLifeBits (Gemmell *et al.*, 2002), and the more access and retrieval oriented Iolite (Rothrock *et al.*, 2006) and Feldspar (Chau *et al.*, 2008).
- within different (often single) context metaphors, for instance Contact Map (Nardi *et al.*, 2002), TimeScape (Rekimoto, 1999) and LifeStreams (Freeman and Gelernter, 1996), and
- irrespective of format and applications, such as Chandler (OSAF, 2003) and Haystack (Huynh *et al.*, 2002).

In order to better support ubiquitous information-interaction, Pervasive Personal Information Spaces cannot restrict itself to a single concept or view as a

foundation for viewing, querying and interacting with personal information spaces. Flexibly incorporating a wide range of techniques and approaches can support information integration, automation, flexible visualisation and interaction, querying and sense making in a contextual and fluid manner. The objective is to move beyond simply creating an integrated digital environment, in order to create rich associative information spaces and personalise ubiquitous information interaction. Several of the ideas considered (on their own and in combination) for Pervasive Personal Information Spaces are at this stage new to developments in information management.

Like Active Documents and Haystack, Pervasive Personal Information Spaces aims to work in the ubiquitous computing environment. Both actual and contextual information is integrated and shared across devices. However, unlike Active Documents, Pervasive Personal Information Spaces aims to emphasise visualisation of information according to the user's entire personal work context, as opposed to delivering documents and services according to the user's environmental context alone. Haystack's presentation of information is through more familiar list-based views. Agents create these multiple views, collecting information together according to specific user and system defined ontologies.

Pervasive Personal Information Spaces places emphasis on "*informal and fluid document organisations*" (Dourish *et al.*, 2000), similar to Placeless Documents, which makes use of personal and universal properties, and MyLifeBits. However, user-subjective details and other properties can be expanded on by incorporating specific contextual details with regards to device, time, location, categories, people, goals etc. and by providing views that can be adjusted according to these contexts. Pervasive Personal Information Spaces means to explore the "five W's" of context suggested by Abowd and Mynatt (2000) to this purpose. These contexts are yet to be worked out in detail. Explicitly defining and describing the contexts as they affect user information work, the research investigates how they can be employed to support contextual information-interaction.

Pervasive Personal Information Spaces also focuses on multiple contextual, flexible views. Many previous developments focus predominantly on one or two contexts to investigate their usefulness in information management, e.g. Contact Map presents information using social networks, TimeScape use a temporal-spatial representation, TimeSpace uses activity-oriented temporal visualisations,

and ROOMS employs task/activity based views. Though MyLifeBits aims to provide multiple visualisations on user information, it currently only leans towards several time-based result views. Providing versatile tools can then allow users to manipulate the various contexts, information details and associations, visualisation styles, as well as annotate and illustrate information, query and apply filters. This personalises information interaction to the user's current work context. Some of these ideas and tools build on the research into Dynamic Queries (Shneiderman, 1994), NaviQue and TimeSpace.

Though systems like TimeScape, Haystack and Chandler offer long-term information and knowledge management solutions, they do not focus on the issue of managing personal information over a lifetime. An important aspect of contextual, flexible views in Pervasive Personal Information Spaces is that their pictorial representation of activities and activity trails can support meaningful creation and access of personal archives or long-term information storage. The archived views would essentially emphasise valuable information through usage trails, bring together distributed information, and provide the digital context to all the items used for easier long-term access, which alleviate some of the issues of personal digital archiving explored by Marshall (2007).

Haystack and Chandler provide multiple views on the same information, uncovering information relationships. Pervasive Personal Information Spaces seeks to emphasise views that are more graphical in the presentation of information to implicitly show their context and associations. The emphasis also lies on user activities and user work, far more than on information or knowledge management. The user's activity context therefore becomes important here. By applying Activity Theory to ubiquitous personal information interaction, Pervasive Personal Information Spaces hopes to shift interaction from a lower-level task-based approach to a higher-level activity-based approach.

Haystack and Placeless Documents employ detailed information structures to support multiple views and information relationships in the former, and personal and universal properties in the latter. Similarly, Pervasive Personal Information Spaces requires a detailed information structure, as it caters for information accessed on all of an individual's devices. Alongside details on information items, Pervasive Personal Information Spaces means to store details on a range of other 'information objects' relating to goals, activities, people, contexts, information

sources, annotations and workspace markings, and relate these back to each other and the user's work.

In working with multiple devices, Pervasive Personal Information Spaces seeks to adapt information to device and context, similar to the goals for Active Documents. At the same time, Pervasive Personal Information Spaces seeks to further allow interaction with information through different styles (e.g. agents, direct manipulation, adaptive techniques) to support automation, interaction preferences, and user work on different devices.

Iolite and Feldspar emphasise associative retrieval, similar to context-based, flexible views envisioned for Pervasive Personal Information Spaces. Iolite and Feldspar emphasise association tracking, whereas Pervasive Personal Information Spaces seeks to emphasise their visualisation. The former interfaces are textual, losing the implicit impact graphical visualisation of context can have as well as the ability to support information browsing and discovery. On the other hand, Feldspar offers a more direct information retrieval through the selection of specific associations. Consequently, Pervasive Personal Information Spaces and the ideas underlying Feldspar may complement each other well. Iolite and Feldspar's focus is nonetheless on associative information retrieval alone, whereas Pervasive Personal Information Spaces seeks to support user work, work continuity, navigation and interpretation. This is especially important as ubiquitous personal information-interaction can benefit from personalised, contextual and associative spaces of information that more implicitly support activity continuity, navigation of personal activity spaces (as described by Benyon, 2001), social navigation, information foraging and sense-making.

The strength and uniqueness of Pervasive Personal Information Spaces comes from exploring and utilising several key new concepts in combination: information integration across personal devices, multiple flexible views according to multiple contexts (including user activities) and visualisation styles, and detailed information capture and relationships. This allows Pervasive Personal Information Spaces to support views of the information space that are highly user-subjective and that match the changing nature of an individual's work and work context. These features can allow for a personalised visualisation and interaction experience with information spaces, that current research has not yet taken full advantage of.

2.9 SUMMARY

A broad range of research provides the context for the work on Pervasive Personal Information Spaces and informs the research into improving ubiquitous personal information interaction. Various frameworks and theories highlight the need to incorporate user activities and contexts in ubiquitous information-interaction. User abilities and individual differences provide insight into personalising information organisation and visualisation to better support information behaviour (including information access, navigation, foraging, sharing and sense making). The characteristics and device particulars of the ubiquitous and pervasive computing environment, as well as the models and techniques of information organisation, presentation and interaction inform the design and implementation of Pervasive Personal Information Spaces. Ubiquitous personal information-interaction further exposes many issues that are important to consider when developing and deploying Pervasive Personal Information Spaces in the future for real world use. Related systems reviewed in this chapter emphasise certain aspects and approaches in supporting information management and knowledge access, but do not provide personalised visualisation and interaction with information that incorporates user contexts in rich, associative information spaces. In addressing the limitations of previous research, Pervasive Personal Information Spaces therefore aims to:

- Explore, define and describe the contextual information that captures details of the user's information work, expanding on Abowd and Mynatt's (2000) "five Ws" of context and Bergman *et al.*'s (2003) user-subjective details.
- Support information-interaction according to user contexts and high-level user activities by providing multiple contextual, flexible views that visualise the user's information space to match their personal, changing work context and information needs. Existing systems largely only focus on one or two contexts or visualisation styles to present information.
- Provide versatile tools to visually manipulate and query views to match the current work context, similar to some of the goals of Haystack, but from a visual perspective.
- Present information graphically to implicitly show the contextual and associative details and information relationships, which can more naturally

support associative information retrieval, contextual information access, information foraging, digital archiving, social navigation and sense-making. Many existing systems only offer partial support for the variety of user information behaviour natural to personal information interaction (e.g. Feldspar focuses on associative retrieval, NaviQue focuses on navigating and querying a visual workspace).

- Integrate information according to multiple devices, automate processes, capture information details and adapt information to device, similar to Haystack, but with activity continuity in mind.

The objective here is to provide an integrated approach to support personal information interaction by personalising the information-interaction experience, matching it to the user's changing work context, visualising the associative information relationships and naturally supporting various user information behaviour.

The next chapter conceptualises the idea of Pervasive Personal Information Spaces, exploring and describing the role that activities and contexts can play in ubiquitous personal information interaction. The chapter then proposes the Spaces model, a framework for developing Pervasive Personal Information Spaces, as a starting point to addressing limitations in previous research.

CHAPTER 3 – CONCEPTS, MODELS AND REQUIREMENTS

PERVASIVE PERSONAL INFORMATION SPACES

3.1 INTRODUCTION

This chapter introduces the concept of Pervasive Personal Information Spaces, as developed and investigated in this thesis. The chapter first defines the concept before exploring and describing the importance of high-level user activities and work contexts in Pervasive Personal Information Spaces. As such, the material contributes to the understanding of how activities and contexts can help relate electronic information in a way that allows information presentation and interaction to match users' individuality, real world activities and work contexts. An example persona and activity-oriented scenarios follow, as a means to explore how Pervasive Personal Information Spaces would function in the real world.

The chapter then describes the Spaces model, the crux of the thesis. Spaces presents an over-arching model of a Pervasive Personal Information Space solution that aims to address the limitations of prior work described in Chapter 2. The thesis proposes the Spaces model as a framework for creating integrated digital information environments tailored to users and their activities, with the aim of providing users with better ubiquitous access to their information spaces.

Finally, functional and non-functional requirements are formulated for an implementation of the Spaces model. Designs and implementations of the model were later engineered incrementally in accordance with these requirements, which focus on integrating the user's distributed information space, supporting automation and communication, and developing flexible views, while also considering quality issues and implementation constraints.

3.2 PERVASIVE PERSONAL INFORMATION SPACES

The research background has identified the theories, user and information context, the computing environment, models and techniques, related systems and issues of relevance to Pervasive Personal Information Spaces. But what are Pervasive Personal Information Spaces exactly? The idea of Pervasive Personal Information Spaces focuses on bringing together electronic information scattered across user devices, building from the work on designing and developing *integrated digital work environments* (Kaptelinin and Czerwinski, 2007), examples of which include the previously reviewed Haystack and Chandler. This distributed electronic information is a sub-set of the user's *personal space of information* or *PSI* (see

Jones and Teevan, 2007 and Jones, 2008) emphasising electronic information items on personal devices, and excluding paper documents, computer applications and tools.

The goal is to provide individuals with access to this electronic information according to their high-level activities and information contexts, without being too constrained by the actual physical location of e-documents, the relative isolation of different personal devices, and the limitations of rigid hierarchies of information items. All information interaction, such as information visualisation, access, retrieval and annotation, would be unique to the user and their work context.

Accordingly, a working **definition** of a single **Pervasive Personal Information Space** is as follows: A Pervasive Personal Information Space is an integrated, digital information environment that brings together the electronic information distributed across all of an individual's computing devices. The Pervasive Personal Information Space provides the user anytime-anywhere access to his/her information space through context-based flexible visualisations that personalise his/her activity work and information interaction.

Similarly, a Pervasive Information Space is essentially the same type of integrated, digital information environment offering contextual, flexible views on information. However, a Pervasive Information Space can be constructed for different user domains, not only personal information spaces. The emphasis can be on different aspects of user information interaction according to their importance in the domain.

The concept of Pervasive Personal Information Spaces in this research has evolved from many factors and changes in the use of computing devices and the computing environment over the last one and a half decades. These include:

- the accumulation of ever-larger sets of information by individuals, that comprises of different media, authored and accessed through different applications,
- the change from the use of a single personal device to the ubiquitous use of multiple devices,
- the personal, contextual nature of created and gathered information, and

- the relative inflexibility of many personal information management tools currently used in this changing computing environment.

These considerations affect user information interaction and led to the idea of creating an interaction experience tailored to the user to better support ubiquitous access to personal information spaces, which forms the basis for the research questions. The Pervasive Personal Information Spaces concept further carries on from previous research and work on TimeSpace and activity-based temporal visualisations of personal information spaces (see Krishnan, 2003 and Krishnan and Jones, 2005).

Relevant developments in the research area show that the research questions and the underlying ideas are largely unexplored, particularly in combination (see section 2.8). There seems to be a need to integrate users' scattered information spaces and allow them to work naturally and flexibly according to their individual activities and contexts (e.g. their high-level work, their individuality and personal preferences, where they are, the devices in use, the people they are working with, their goals and time-frames). This seems especially the case, as existing information interaction is often heavily device-bound, generic and not flexible enough to shape itself to the user and their work, as also seen in the focus group study conducted for this thesis (see Appendix A).

The combined ideas for incorporating user activities, work context and flexibility into creating the personalised interaction experience led to the hypothesis that context-based flexible views could provide better contextual, ubiquitous access and visualisation of information than current single-device metaphors. Studying these ideas allow us to explore different ways of tailoring the interaction experience to the user, as well as evaluate how successful they may be and how they can be used to extend current technology.

The small focus group discussion conducted on individuals' use of multiple devices brought forward attitudes and viewpoints that were in accordance with the Pervasive Personal Information Spaces concept (see Appendix A for more details on the study). Participants particularly voiced support for:

- Management of work carried out using multiple devices, at different locations, for a variety of activities.

- Automatic management of information exchanges between devices to keep information up to date, i.e. devices freely talk to each other and share information as necessary without continuous user intervention.
- Information access that is independent of location and device, with information being readily available whenever and wherever.
- Different perspectives offered of the same information, expanding on and decreasing reliance on purely hierarchical models of organising information.
- Facilities for archiving and retrieving old sets of information items according to time and context.

Introduced to the concept of Pervasive Personal Information Spaces, participants felt that its underlying ideas would help lower human error, reduce information management overhead (particularly w.r.t. creating backups and synchronising devices), provide a more natural way of interaction (through multi-device and multi-context support), and allow users to focus more on the actual work carried out.

After defining and exploring Pervasive Personal Information Spaces, there are several important questions to consider in developing the concept:

- What are some of the central concepts in Pervasive Personal Information Spaces?
- How would Pervasive Personal Information Spaces function in the real world?
- What characterises Pervasive Personal Information Spaces?

This section now discusses the concept's focal points, namely personal information spaces, high-level user activities and contexts in information work, before giving a glimpse into how Pervasive Personal Information Spaces would function in the real world. In the next section, the Spaces model then presents the characteristics of the concept as a framework, with the goal of addressing the limitations of related research.

The conceptualisation and research into Pervasive Personal Information Spaces is supported by the wide-ranging background research explored in the previous chapter. As the thesis explores Pervasive Personal Information Spaces through its central concepts, the Spaces model, and interface and interaction designs for an

example implementation, the text will refer back to the relevant research reviewed in chapter 2 that informed the work.

3.2.1 CENTRAL CONCEPTS IN PERVASIVE PERSONAL INFORMATION SPACES

The Pervasive Personal Information Spaces concept starts with an understanding of the selected user domain of personal information collections, user activities and use contexts, and how their characteristics can help with matching information visualisation and access to the user and their computer-supported work.

PERSONAL INFORMATION SPACES

Pervasive Information Spaces can be suitably created for a variety of domains, such as an individual's information collection on his or her personal devices, a knowledge worker's work-related information space and a user's access to the subject-oriented contents of a digital library. These user domains have a significant influence on the way Pervasive Information Spaces would be implemented, both with respect to the kind of views that are presented of the information space and the information details presented in the views. The various domains relating to electronic information spaces can be considered individually or as a group of related domains.

Personal information collections and user interaction with their own information collection provide the best starting point for grasping how information interaction can be tailored to the user and his/her work. The information space and interaction is unique to the individual. There are no business-organisation type protocols of relevance to the domain, although simple user-defined protocols can exist for sharing information with friends and family.

To understand the domain, we have to explore it in detail. Characteristics of the domain context for personal information collections are outlined next with details of their effect on modelling and developing Pervasive Personal Information Spaces. These domain characteristics for personal information spaces are chiefly informed by the background literature (see section 2.3), experience and observation, as well as some findings from a focus group interview (see Appendix A) conducted early on during the research.

Who? Users

The users within the selected domain largely include the entire set of computer users. Hence, there are no real generalisations to make about the group's characteristics. Instead, what's important here is that each user's individuality (such as their personality, experiences, abilities and background), unique collection of information, interaction, work styles and activities characterise the information space. Within this domain, users' activities and collected information are highly personal and hold meaning to the user. All activities track important aspects of the users' daily lives, from studies and hobbies to photos and finances. A Pervasive Personal Information Space will therefore need to adapt itself uniquely to the individual.

What? Work

The work carried out within this domain can relate to study, personal knowledge work, business or professional work, creative and hobby-related activities, and home management. This work can be seen as made up of high-level user activities (discussed in detail in the next section). The distributed information space would encompass multiple activities, which can be ephemeral, short-term or long-term; recurring, continuous or intermittent; individual or collaborative; and can have specific goals and milestones and be related to one another. In carrying out computer-supported activities, individuals frequently multi-task, switch between activities, communicate and collaborate, and deal with interruptions as well.

Furthermore, an important aspect of user activities within this domain is that they often have both real-world (e.g. actual conducted interview) as well as electronic components (e.g. interview documentation) which are closely integrated. User work in the physical world further has a detailed context, with information that is heavily annotated - both naturally and/or intentionally - through user interaction (e.g. marks, attention grabbers, notes, contact details, post-its, diagrams, physical placement, to-do lists, colour-coded tags and so on). As a consequence, Pervasive Personal Information Spaces have to allow users to work according to their activities and relate the electronic context with the users' real-world work context.

Which? Information

Information items within this domain are personal, and relate back to an individual's own work, interests, characteristics and daily life. The user knows the background of the created and gathered items, and the information collection as a whole. Information items are of varied media (e.g. documents, photos, music) and come from multiple sources (e.g. self-authored, online sources, friends). Some information items would be kept highly private and secure (e.g. finances), whereas others may be shared (e.g. pictures). Information items can further be the central focus of work (e.g. presentations, articles) or provide additional details about an item or the work context (e.g. notes or to-do lists).

A further important aspect of this domain is that information is often distributed across multiple personal devices (and user accounts), such as desktops, laptops, PDAs and mobile phones. In interacting with electronic information, information visualisation, access and retrieval become essential, as well as overviews and details of the information space and tools to annotate the information, as shown in HCI research in the previous decades.

Personal information collections invariably grow over time. The evolution of a collection is unique to the user and implicitly provides details as to the direction of change within the information space. The changing information space mirrors the user's changing interest, experience and continuous learning, varied and changing roles, and changing work contexts. Users create various versions of information items, deleting some items and adding others. Most of the information items in the collection will be kept for the long-term (e.g. photos, finances, emails) and periodically information would get archived. Pervasive Personal Information Spaces have to therefore manage a large collection of information and show the detailed relationships between items, as well as visually present the unique information trails within user activities.

Where and When? Environment

The environment for personal distributed information spaces is ubiquitous and encompasses activities carried out at home, place of work or study, libraries and internet café's, as well as while mobile. The information space is distributed across multiple devices (fixed and mobile, running various operating systems, and with various degrees of network connectivity), across various user accounts (long-

term as at home and brief as in libraries or internet cafés) and at multiple physical locations. Work can be done at any time, over short or long sessions, and is often portable. As such, Pervasive Personal Information Spaces need to manage information collections distributed across different personal devices, provide users with continuous anytime-anywhere access to their information, and deal with issues of privacy, security and access control.

Why? Goals

User goals in interacting with personal information spaces vary from organising information items (low-level) to organising a group holiday (high-level). Goals are unique to the user and their activity context, and can be fixed or vague and change with time. There may be many different current goals, with associated activities, people, milestones, events and so on. Each goal can also often have a real-world counterpart or activity component. Even when goals are not clearly defined, they bring various pieces of information together as part of the user's work context. Pervasive Personal Information Spaces need to reflect that to allow users to fully attend to and direct their work.

How? Devices, tools and constructs

Devices in use within the domain include desktops, laptops, PDAs, mobile phones and a variety of small digital and storage devices. These devices vary in mobility, connectivity, processing power, memory, operating systems, interaction styles and use. Yet, there are similarities between the devices in the activities they support and an overlap in the information of interest.

Desktops and laptops are characterised by limited to medium level of mobility, medium level of task switching, high processing power and ample memory. They are used for information management, communication and co-ordination (e.g. e-mail, video calls), authoring (e.g. documents, pictures), information access (e.g. personal and shared information repositories, the WWW), and managing transactions (e.g. shopping, finance). Information created and shared with these devices are re-visited often and stored for the long-term.

PDAs are characterised by high levels of mobility, high level of task switching, medium processing power and memory. They are mainly used for communication and co-ordination (e.g. schedules, e-mail as well as phone calls on smart phones),

authoring (e.g. notes), information access (e.g. reading and browsing), and managing transactions (e.g. accounts). These activities can still be interrelated in PDA use, though less so than in desktops and laptops.

Mobile phones are characterised by high levels of mobility, high level of task switching, limited processing power and memory. They are used mainly for communication and co-ordination (e.g. phone calls and address book), authoring (e.g. messages and photos), and information access (e.g. limited browsing). Here, activities and information items are highly context related and often not as closely related to each other as much as they are related to the general activities of the user in the real world and across devices. A large amount of the information generated through mobile phone use is however ephemeral.

Other digital devices and storage devices are characterised by high levels of mobility, very limited to no processing power and varying memory. Digital devices such as digital cameras or mp3 players are used in a very task-specific way. Storage devices are used for temporary storage, back-ups or information archiving, as well as for transferring information between devices and locations.

A variety of applications are used to access information on desktops, laptops and PDAs for viewing, editing and sharing. In the current environment, this information is largely organised and managed through hierarchical folders, with some use of web services such as online email clients, calendars, wikis and servers. Information is retrieved largely through hierarchical folder constructs, organised shortcuts (e.g. on the desktop or in a file) and keyword searches.

As such, the multitude of devices, applications, the various interaction styles as well as device related constraints on information presentation and access, would pose challenges to developing Pervasive Personal Information Spaces for this domain.

HIGH-LEVEL USER ACTIVITIES

Studying personal information spaces sheds light on how to shape Pervasive Personal Information Spaces. Integral to user interaction with personal information spaces are high-level user activities and Pervasive Personal Information Spaces seek to visualise information primarily according to the activities individuals engage in using their computing devices. We start by defining and describing what is understood under ‘activity’ in this research, before

specifying how the idea of ‘activities’ characterises and changes the perspectives offered on an individual’s information space. The activity-focus in this research takes into consideration Activity Theory and Activity-Centred Design (reviewed in 2.2.2).

Defining ‘Activity’

A working **definition** of **activity** in this research is as follows:

An activity is any high-level task, area of interest or project of an individual, which is characterised by varied information-interaction over time towards achieving a set of goals. Information-interaction for an activity can take place in the real and electronic worlds. Each activity encompasses an assorted collection of related information objects or artifacts, tasks and actions. An activity’s information objects are related to each other implicitly through the information context, use context, time of use, user actions, user attention and goals. Activities can be related to one another, and together form and reveal an individual’s changing information space.

When activities are referred to in this research and thesis, they always match this definition. Examples of activities include those supporting project work, individual interests and everyday life management. Project work, including professional and academic work, can include for instance writing a biology essay, researching and developing an architectural design for a new museum, and carrying out an honours project. Examples of individual interests and hobbies are researching and collecting world music, creating and maintaining a personal blog, and looking up rock-climbing information. Finally, everyday life management activities can include tracking on-line shopping activities, planning a family trip and managing family photos.

Activities within this research have the following characteristics:

- Activities are high-level areas of interest or abstractions of work.
- Activities have associated goals (short term and long term) and contexts of use (relating to people and teams, locations, devices, time frames and so on), and are composed of goal-directed actions.
- Activities are user-specified and unique to individuals. Activities can be created, tracked and managed actively (e.g. collecting digital artwork) and

passively (e.g. tracking technology news read by the user through several web-sites).

- Activities can be ephemeral, short term or long term. They can involve intermittent, continuous or recurring work.
- Activities change and evolve with time. Different activities and sets of activities become the focus of attention at different times, and certain activities can further have the main focus according to the device in use or current location etc.
- Activities encompass a wide variety of information objects and artifacts, and have both electronic (e.g. interview documentation) and non-electronic/real world components (e.g. actual interview).
- Activities can be related to each other. They may overlap and share information objects, and consist of sub-activities.
- Activities specified by the user can be categorised under a set of generic activities or according to the information collected.

Generic activity categories can include activities of information gathering, information generation, collaboration, communication, information management; activities relating to work, study, home, or leisure; and socially specified categories such as travel, retail, health, finance, professional, education, hobby and so on. Information collected can be classified as active or passive; structured, semi-structured or unstructured; ephemeral, working, archive or prospective; real-world or virtual; personal, organisational, public or person-less; and according to media type.

Activities as part of the information space

Most of the work individuals carry out using various computing devices is part of some kind of high-level activity. In representing the individual's electronic information space according to these activities, the visualisation matches the work of the individual more closely, supporting context-based tracking and retrieval of information. (Lamming and Newman (1992) support this, stating that automatically tracked activities can offer many time and event-based contextual cues for retrieving information.) The information space represented over time as a changing set of user-specified activities further lends itself to interpretation by the user of his/her individual work and behaviour.

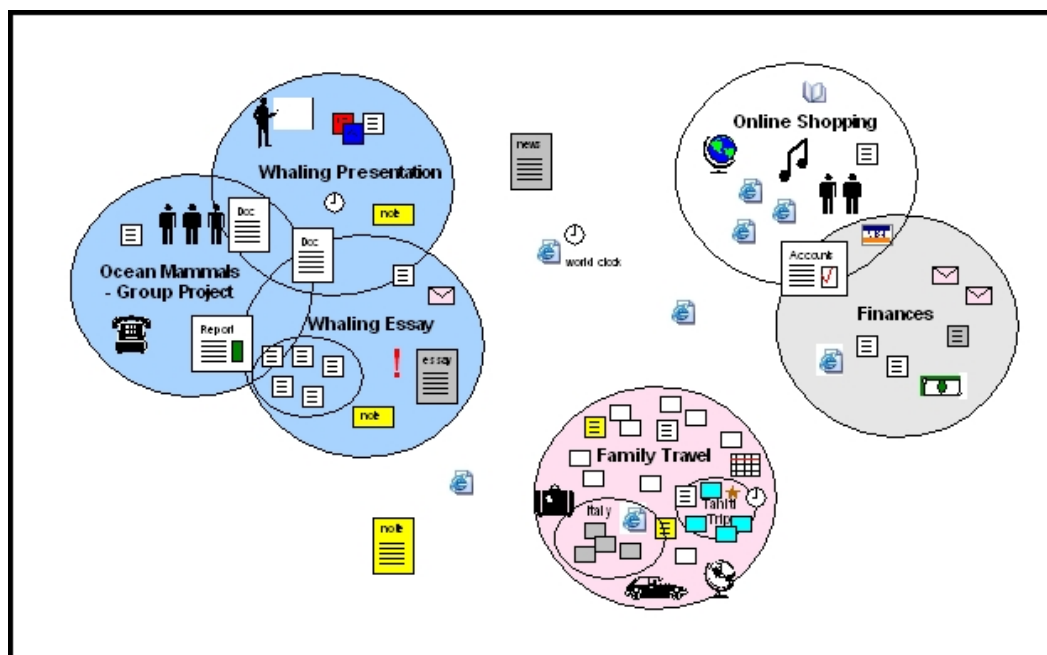


Figure 3-1: Example segment of a user's information space

Figure 3-1 provides a simple example of part of a user's information space at a given time and will be used to look at how activities work as part of the information space. The information space segment consists of several activities (such as Whaling Essay and Online Shopping) and various types of information (such as reports, contacts, phone calls, photos and notes).

Information created, gathered and accessed by individuals can easily belong to several activities. For example, an article researched for an essay might also be of use to another project later on. Consequently, activities should be able to share information items. However, not all information accessed and gathered by an individual might belong in an activity or the individual might not wish to track certain work (such as world time information or today's weather report). The representation of the information space is a personal view on the information that individuals gather and create. The representation should therefore allow certain information items to be tracked outside of any specific activity and also allow individuals to choose not to have certain information registered as a persistent part of the information space.

Within this idea of activities and to support further flexibility within the representation of a user's information space, the following view can be taken of the information space and the activities that form part of it. The information space

consists of a multitude of activities and the information items they contain, as well as information items that are separate from any single activity. Activities can overlap when they share the same information items (such as the activities Online Shopping and Finance do in Figure 3-1). Activities can further be related to each other (like the activities Whaling Presentation and Whaling Essay). In the figure, these related sets of activities have the same colour.

Activities can also consist of sub-activities, where these sub-activities further group information items together under a specific area of interest within the larger activity (such as the trip to Tahiti in the Family Travel activity). Another interesting aspect of activity work is that document relationships change with time within activities. For example, several documents or information items that the user is working on at a given moment can be inter-related for that part of the activity. The same documents might relate to other documents at other times within the same activity, or to other documents in different activities at any point in time.

A categorisation based on activities bears a superficial similarity to categorising information in folders, where a folder matches an activity for instance. However, the similarity ends there, as presenting information according to activities differs from folder-based categorisation in a variety of ways. The differences and strengths of an activity-based paradigm allow an application to provide rich, user-adaptable perspectives on the information space. Activities do not rigidly categorise information and bury them in a hierarchy, but track work with information objects, actions, work overviews and progress, information trails and supporting contextual information. The visual aspect of using activities to provide views onto the information space and access to the underlying items really comes to the fore with flexible views to view and filter activity information according to different work contexts and visualisation styles.

At the abstract level, activities track work, interests and behaviour through information and interaction trails, not documents or document categories in and of themselves. Consequently, they lend themselves to tracking that can be largely automated according to user specification. They integrate information across applications at a logical rather than physical level, and more accurately tie together the work in the real world with work in the virtual world. For example

email and phone calls can be associated with related documents accessed across different devices, and annotations and voice notes associated with the actual presentation as well as the electronic presentation slides.

Activity-based focus does not just centre on the electronic world or application-rendered information, but allows concrete information items and documents (e.g. office documents such as reports) to be supplemented by contextual details and annotations that inform the work (such as phone calls, locations, people, reminders and notes) as they too form part of the activity. So although the basic lens used here to look at information is user activity, activities as a central building and visualisation block within personal information spaces allow for a flexible, annotated space with detailed information relationships, that do not sacrifice the work context of the individual.

CONTEXTS IN INFORMATION WORK

High-level user activities are a main type of work context. Work context however also includes other information, such as details about locations, people and time.

A working **definition** of **contexts in information work** in this research is as follows: Contexts in information work provide various cognitive, descriptive and situational details about the user's computer-supported activity and the information the user interacts with. They form detailed, user-subjective information relationships, without which individual pieces of information or documents would stand isolated and lose some of the meaning they can convey. Contexts in information work can be classified as social, activity, information, physical, temporal, goal and device-oriented information, each of which can be identified as a specific context.

This definition moves beyond the idea that "*context is any information that can be used to characterize the situation of an entity*" offered by Dey (2001) to classify what kind of information can be explored and considered as affecting user information work and interaction.

Pervasive Personal Information Spaces seek to support the user's work by complementing the activity context provided in views of the information space with other contextual information. All of the user's work context informs and helps interpret the work, allows easy task resumption by reminding the user of the previous state of work, and also acts as a natural way to retrieve information. We now look at the different types of context and the information they help provide

about the user's work. This builds on the ideas from Everyday Computing, reviewed in section 2.2.1.

Understanding context

Abowd and Mynatt (2000) explained that the user's context can be preliminarily presented according to the "five W's" of context: who, what, where, when and why. These contexts have not been worked out as yet in detail to explain what each context encompasses and how they can be used to improve personal information interaction in the ubiquitous computing environment.

The research on Pervasive Personal Information Spaces proposes seven specific contexts that have a bearing on computer-supported information work. Each gives an understanding of the kind of information Pervasive Personal Information Spaces needs to track and represent to support users in carrying out work according to that work's context. Exploring and expanding the basic idea of "five W's", we obtain the following contexts of use:

- Who? The social context: identity and characteristics of main and secondary users, and surrounding people.
- What? The activity context: activity specification, and perception and interpretation of activity and corresponding actions.
- Which? The information or knowledge context: information items, information relationships, and information sources in use.
- Where? The physical context: location of activity and situational details, or location and situational associations of information.
- When? The temporal context: absolute and relative time of activity and information use.
- Why? The goal-related context: reasons for activity or behaviour, and user goals and attitudes, which can be derived from user's state and other context.
- How? The device context: devices in use, device capabilities and interaction styles, applications used and device connectivity.

Combined this gives us a context for information interaction and use, as well as an understanding of the different perspectives that can be offered on the information space according to the contexts of interest in each situation.

Who? The social context: The social context deals firstly with the main user and owner of the information collection, their identity and roles, characteristics including preferences and level of expertise, activity history. Secondly it deals with details of other people including team members, associates, family members, authors of information looked at by the main user, and general contacts and relevant people in the user's activity environment. The social context tracks details that link information in the user's collection to others (e.g. through authoring, sharing or discussing) and illuminates these information relationships. For instance, tracking the social context would allow users to bring up information items that a friend had shared with them or view information items that they worked on as part of a particular team, linking items directly to the people they relate to.

What? The activity context: The activity context focuses on the high-level activities (e.g. 2003 performance presentation and thesis write-up) and supporting actions (e.g. conversations, window-shopping and meetings) carried out by the user. The activity context brings together all the information items and relationships, actions and notes carried out as part of one activity. The activity context also assists users with sharing work and collaborating on work, as well as interpreting their work and work progress, work style and behaviour, activity history, and the evolution of their activities and their information space. For instance, tracking activity context can allow users to easily switch between activities without having to remember the previous work context, or revisit an older activity to look at how they researched a particular problem.

Which? The information context: The information context (or knowledge context) focuses on the information items used in activities (e.g. documents, e-mails, web pages and photos), information sources (e.g. the WWW, people, libraries, real world objects), information classification and relationships (e.g. relating photos created during the same session to one another, linking notes and actions with specific sets of documents). The information context also emphasises a variety of annotations like reminders, notes, keywords, tags, action markers and diagrams that clarify and support user work. Tracking information context allows users to see information relationships explicitly according to their work (e.g. a user can

easily spot which online real-state pages helped him decide on a particular house purchase) and which actions were performed when working on a project (e.g. a user can re-trace the conversations and emails relating to delegating different tasks in a project to different colleagues).

Where? The physical context: The physical context pertains to details about the location and environment that have a bearing on the user's activity or information items. This can be twofold. Details that can potentially inform user work on computing devices include information about the building or location that the user is in or the activity is carried out in, whether the user is inside or outside, whether the user is stationary or on the move, as well as environmental details such as noise level and light conditions. The physical context, however, can also relate user activities or information objects back to physical, virtual or conceptual locations (i.e. due to their implicit associations to a location in the real world or in the virtual world, or perhaps even a category map). Incorporating these types of details into views of the information space can for example help users in tracking activities carried out in specific locations (e.g. retrieving field study data collected in a specific national park), or information items pertaining to certain locations (e.g. bringing up documents related to a particular office branch or research lab).

When? The temporal context: The temporal context comprises details about absolute time (e.g. for chronological presentation of information) and relative time (e.g. to show that one activity was started just before another, or that a specific information item is always updated after another has been accessed within a particular activity) with respect to activities, events and information use. The temporal context and information relationships provide interesting sporadic, periodic and past-present-future types of information associations and retrieval cues. Tracking the temporal context of user activities can powerfully assist users with interpreting their changing activities and evolving information space, building on previous work and discoveries, as well as making inferences about their progress, behaviour and developing interests from temporal overviews of their activity space and trails of information use.

Why? The goal context: The goal context looks at the reasons users have for carrying out activities and their goals. User goals can vary with activity, time, location and so on. Some goals can be derived from activities, to-do lists, personal and shared schedules, and new events and information of interest, though most goals would be user-specified. Incorporating goals into activity-based perspectives on the information space allows users to stay aware of them while accessing and interacting with information. Goals can be displayed alongside activity information, with reminders, deadlines, milestones and related information objects. When providing overviews of the user's activities, goals and related details (such as 'write and send in progress report by Monday', 'draft submitted' or 'share these photos with Kim') provide users with a quick way of assessing their progress and their commitments, implicitly reminding them of what they've done and what they need to do.

How? The device context: The device context takes into account the devices, applications, and technological constructs and processes used by the user, as well as device characteristics, interaction styles and device connectivity (e.g. connection type, availability of intermittent or continuous connections and approximate indication of next connection time). Tracking the device context can help in adapting information and views to the device in use and available interaction styles. For instance, users can have simpler views of the information space on smaller mobile devices and annotate the views on the go with voice notes.

Utilising contexts

Context-aware applications can use context to present information or services to the user, perform services for the user or annotate information with this context to support information retrieval (Dey, 2001). In Pervasive Personal Information, the goal is to better support ubiquitous access to personal information by supporting high-level user activities. Hence, context becomes chiefly a tool to track, visualise and present information in a way appropriate to user work, i.e. with the contextual details intact for sense making and supporting work continuity. This is in line with the subjective classification and subjective context principles in Bergman *et al.*'s

(2003) user-subjective approach to the design of PIM systems (reviewed in section 2.2.5).

Gonçalves and Jorge (2003) note that with an individual's personal information space spanning different devices and containing large and diverse documents, tools for visualising this information space as a whole are imperative. However, current visualisation and browsing tools do not support finding specific documents well in individuals' large document spaces. In line with the goals and Pervasive Personal Information Spaces, Gonçalves and Jorge therefore voice support for interfaces that provide easy access to active files and that 'tell a story' of documents using contextual and autobiographical information as a more natural and efficient way of retrieving documents.

When views on the information space are shaped by and supplemented with contextual details, they act as information filters that support task switching and resumption, perceiving and interpreting user work and progress, discovering opportunities for taking action or developing an idea, information foraging, information exploration and sense-making, as well as knowledge work. Contextual views can also support social navigation, when users are afforded the means to share views that display their trails of information use and interaction. (Sections 2.3.2 and 2.3.3 explored some of these information activities and behaviours.)

Each of the listed contexts provides insight into an aspect of the user's work that can assist users to stay aware of the context their work is carried out in. They also support contextual visualisation, access and retrieval of information within the user's information space.

Integrating contexts greatly increases their usefulness, as each combination of contexts allows users to look at and interpret their activities in different ways. For example, combining social context and physical context, users can track work according to teams in different departments or countries. In combining the activity and temporal context, users can find out which activities they were engaged in at a particular point in time or see the chronological progress of their work. Considering the information context alongside the device context, users can compare the information items accessed on two separate devices in one view.

In tracking multiple contexts in information work, a system would basically create a record of the user's changing work context. Providing users with the flexibility

to combine and select multiple contexts to shape and filter the views on their information space would allow users to easily assess and answer simple and more complex questions about their work, anytime and anywhere. Users can for instance look at their information space according to a particular set of activities, occurring during a set time frame, in two specific locations, and relating to a particular project team. This annotated information can then be used to implicitly track progress and gain a quick overview as to which team members are working on which pieces of information in which activities during the selected time.

Although certain contextual details can be tracked automatically (e.g. the device in use or information items accessed), others would be largely user-specified (e.g. the goal for a particular activity) if users choose to specify that contextual information. The seven given contexts provide a framework for users to create their own context instances (e.g. home, work, car, shop and France for physical context; desktop and phone for device context; individual contacts for social context) that would be incorporated into the information space, marking and individualising the space.

The above material has mainly explored contexts with respect to information work, to realise Pervasive Personal Information Spaces with current technology in mind. Contexts can be expanded to support far more expansive scenarios, especially with further developments in technology, with enhanced wearable devices and better ways to automatically collect contextual information. We will now look at how Pervasive Personal Information Spaces may work in the real world, with a worked out example to bring together personal information spaces, user activities and contexts. Later chapters detail how user activities and contexts may be represented and incorporated in interfaces supporting information work, what kinds of information relationships will emerge in the contextual views of the information space, and what kinds of details would be gathered for each type of context.

3.2.2 PERVASIVE PERSONAL INFORMATION SPACES IN THE REAL WORLD

After defining and exploring the central topics in Pervasive Personal Information Spaces, it is necessary to look at how we may envision Pervasive Personal Information Spaces working in the real world. Using a provisional persona, an

example scenario, an activity-based scenario, and several snapshots of the activity's work context, we can explore the current situation and its limitations, as well as the Pervasive Personal Information Spaces solution. (Unlike a typical scenario of use, the first scenario presented here will focus on computer-supported information use and interaction at an abstract level for a set of related activities. It details some of the user's context and activities, and sets the stage for a more specific scenario of use and interaction that delves into a selected user activity.)

The following persona and scenario descriptions draw from the studies on user information interaction and management to illustrate the current computing situation. These studies (reviewed in 2.3.2, in the section on *electronic information organisation and management*) provide details relating to device and tool use, folder categorisation and hierarchies, and information management strategies (e.g. information filing, information retrieval, and naming schemes). A small focus study was conducted to supplement these findings (see Appendix A) and further informed the persona and scenario descriptions. The focus group interviews emphasised multiple device use and uncovered information on daily device interactions, information storage on multiple devices, synchronisation processes, as well as user interaction preferences, attitudes and frustrations.

Provisional persona "Lisa"

Lisa is a postgraduate student in Computer Science and uses several computing devices in her everyday life. She uses a desktop computer at university for her research work, a laptop for work and leisure at home or sometimes on travel, and library computers to look up database articles and books. She carries a PDA with her everywhere, which she often uses for tracking appointments and making notes. She also has a mobile phone with her at all times and owns a digital camera. Lisa uses a pen drive to carry back-ups of her current work and transport specific documents between devices or locations. An external hard-drive further serves as a means of archiving information for the long-term.

Lisa has been using computers extensively for the last five years and feels comfortable with technology. Lisa's biggest frustration is with resuming various activities. As they involve numerous items of information and trails of ideas, she finds that her activity continuity is interrupted when returning to her work. Some elements are invariably lost

when she tries to recall all the details of her work and information interaction from a previous session. Lisa's goal in working with her devices is to efficiently carry out her work and keep track of her study and leisure activities. She seeks to keep her documents and notes organised together and easily available with minimal effort. A list of ideas and notes close at hand helps remind her of things she wants to act on or work into her write-ups or presentations. Lisa also appreciates knowing what she's working on, so that she can track her progress or resume an activity that's been on the back burner too long.

Her computer-supported activities include, among others, completing courses and doing research, as well as tracking her interest in NZ wines and vineyards, and creating digital scrapbooks of her travel photos and sharing them online with her family and friends. Her goals for these activities involve carrying out assignments and research, learning new skills, exploring her interest in NZ wines, developing a photo diary, and sharing her adventures with friends. In carrying out her activities, Lisa takes on a variety of roles such as student, researcher, photographer, hobbyist and group member, which all influence her activity work, work style and interaction, and behaviour.

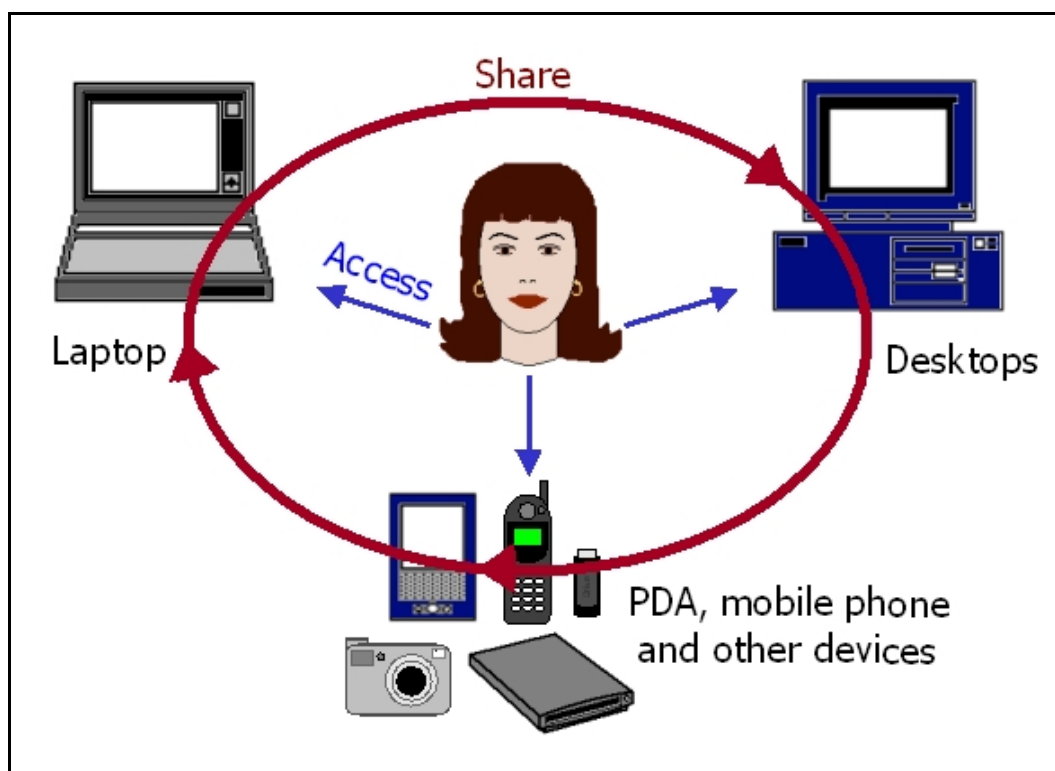


Figure 3-2: Lisa's devices

Lisa's situation is common. Like many people these days, Lisa uses multiple computer devices in her daily life. She interacts with electronic information through a variety of different devices such as desktops at university and libraries, her home laptop, a personal digital agent (PDA), mobile phone and other devices as shown in Figure 3-2. These devices support everything from communication, information gathering, support in study and work, shopping and hobby related activities.

Scenario

Lisa engages in various activities related to her interest in NZ wines and vineyards. She tracks the wines from several prominent NZ vineyards through their web-sites, attends various gatherings and visits vineyards as part of a newly started wine-tasting group, and also writes a review column for a wine-tasting web-site's newsletter once a month that is based around these gatherings and visits.

Lisa's activities have both real world and computer-supported aspects. She uses her devices to track web-sites and gather information, communicate with the group's members, organise events and vineyard visits, and write her newsletter column. The real world aspect of her activities (such as gatherings, visits and conversations) informs and is in turn informed by her device use.

Lisa's work's social context takes into account the members of the wine-tasting group, as well as the people she communicates with about related events, vineyard visits and the newsletter. Her activities related to her interest in NZ wines are inter-related, have associated goals and incorporate numerous information objects (such as web-sites, wine-lists, emails and phone conversations about events and vineyard visits, newsletter review documents, pictures taken on visits and so on). Her work context further extends across multiple devices, different physical locations, and varying activity time frames that include events and due dates.

Activity scenario for "Newsletter column" activity

Lisa is currently working on her latest column for a special issue of the newsletter, which focuses on the history of specific wines and vineyards in New Zealand. She prefers to do most of her reading and writing at home, and to research her material on her laptop or in the city library. Normally, Lisa spends about a week or two preparing her write-up for the end-of-the-month release of the newsletter.

Lisa pays a visit to the city library early on. She saves references to interesting books

and articles she finds through the library on her pen drive, makes notes of them on her PDA and takes some books out. She'll be working all the material into her write-up at home. Lisa tracks down further, on-line research on the laptop at home, printing material out to read and highlight.

Lisa also has phone conversations with a vineyard owner and a friend who works as a sommelier in a local restaurant to get feedback on her angle for the column. She further visits the local vineyard for pictures and any further things of interest. She notes down any significant ideas and insights from the conversations and visit on her PDA and on paper to incorporate into her write-up.

Once her column is written up, she emails it out to the newsletter editor. The editor asks for a few minor changes this time before adding it to the newsletter. After the newsletter is sent out, Lisa backs up all her documents to the external hard-drive as she does every time after completing an important activity or project.

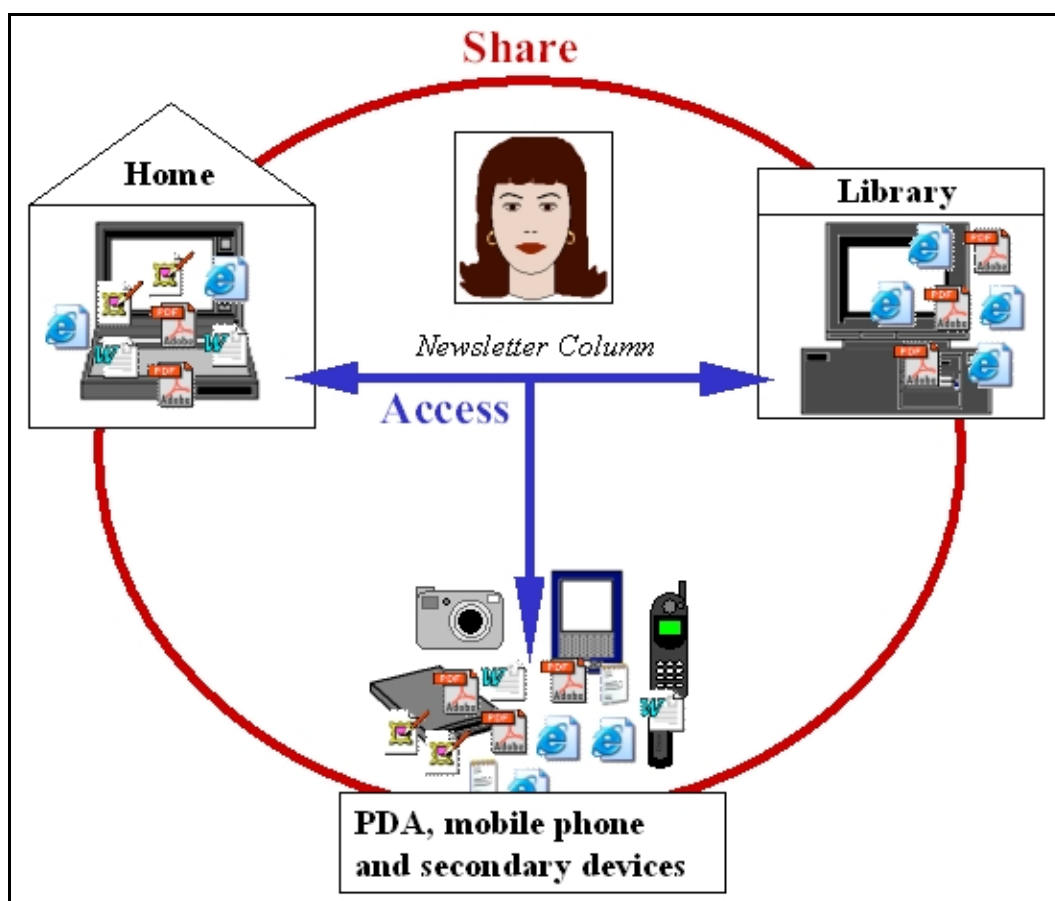


Figure 3-3: Separation of information and information interaction due to location and device for Lisa's newsletter column activity.

Lisa's information space covers a variety of activities and spans different locations, as well as devices. In the given scenario of use, her articles are on her laptop and in print form, her research takes place in the library and at home, her column-in-progress is on the laptop, while related notes, pictures, communications and her archived documents are on her PDA, mobile phone and secondary devices (see Figure 3-3). Her desktop at university is not used for these activities and so carries no related material.

Lisa's work context further involves different events and people, and relates and informs her work over time. Figures 3-5 to 3-7 illustrate this by presenting simple snapshots of the work context relevant to Lisa's writing activity on three specific days of the activity.

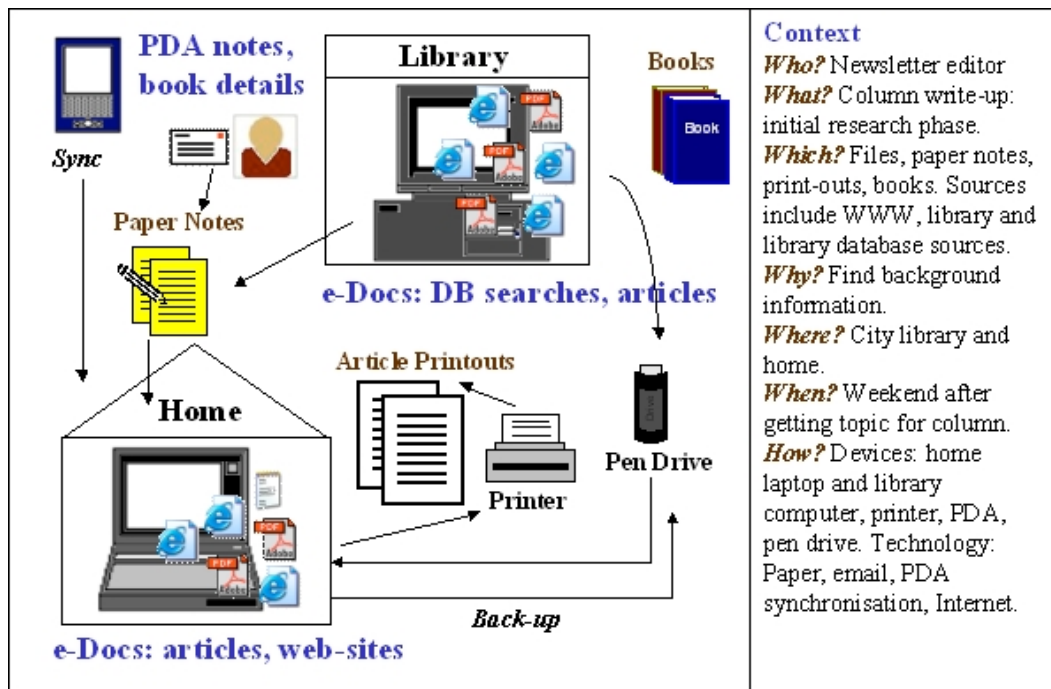


Figure 3-4: Context snapshot 1

Time

Context snapshot 1 for "Newsletter column" activity (Figure 3-5)

The first context snapshot summarises Lisa's initial research phase, when she looks up material for her column at the city library and at home on a weekend. As this month's newsletter is a special issue, her column entails more work than usual for Lisa. She writes out notes on paper on the general topic she was asked to write by the newsletter's editor, before performing searches on the library database. She also wants

to get out two specific books from the library that she's looked at before for another activity, but as she doesn't remember what they were, she tries to track them down again. She gathers articles and references, which she stores on her pen drive, and uses her PDA to jot down notes and book locations. She also writes a to-do list and some further ideas on paper, and checks the books she's interested in out of the library, before heading back home to work through the material on her laptop. At home, she prints out the articles she wants, synchronises her PDA with the laptop, tracks down a few relevant web-sites, locates a couple of bookmarks for sites encountered for a previous column write-up and compiles the references she's used. She then backs-up her work on her pen drive.

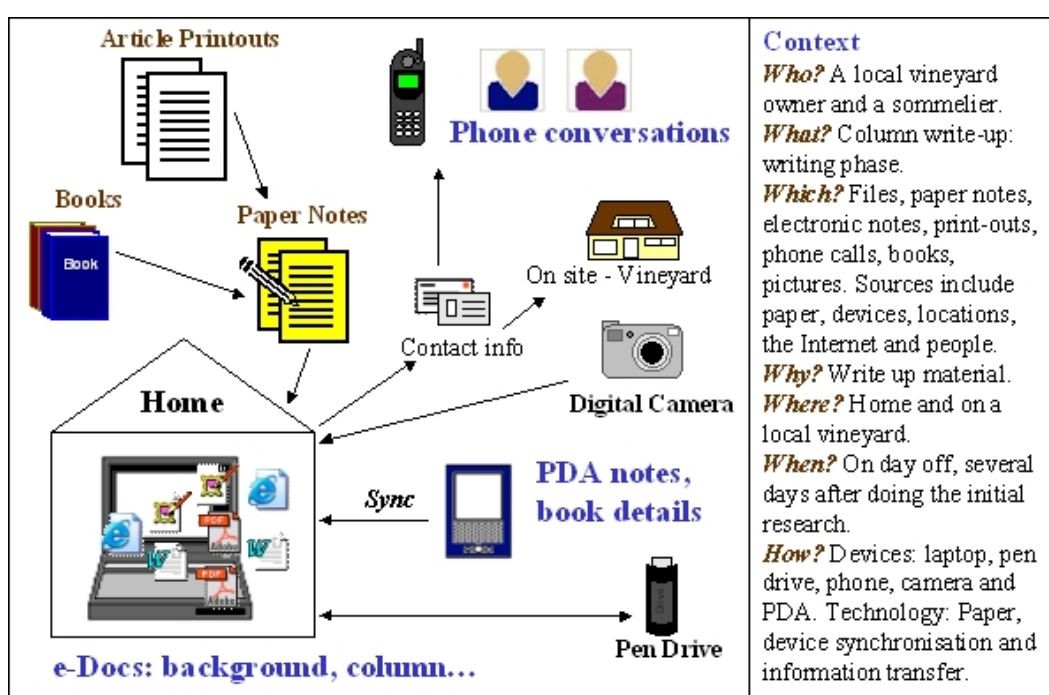


Figure 3-5: Context snapshot 2

Time

Context snapshot 2 for "Newsletter column" activity (Figure 3-6)

The second context snapshot looks at several days later, when Lisa has some time off to focus on her write-up at home. At this point, she refers to her paper notes, looks through the books and article printouts from her last session, makes notes and writes up the major part of her column on her laptop. She also calls up her sommelier friend to talk about the selected wines and vineyards she's looking at and writes up some of his views on paper. The same day she tracks down the contact details for a local vineyard owner she's met a few times from an old email invitation for an event, calls her up and visits her vineyard in the afternoon. Lisa has a longer chat with her there

and takes some pictures of the place with her digital camera. She makes a few notes on her PDA and keeps some ideas in memory to follow up on later. In the evening, Lisa syncs her PDA to her laptop, works her notes into the column, and backs up her work.

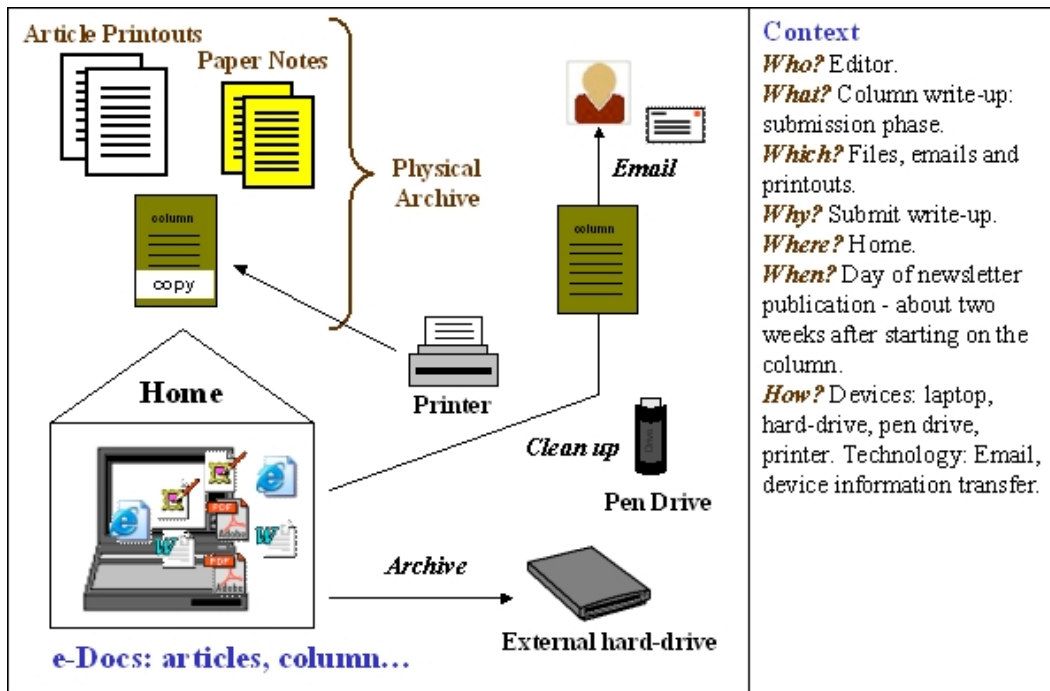


Figure 3-6: Context snapshot 3

Context snapshot 3 for "Newsletter column" activity (Figure 3-7)

The final context snapshot now considers the day Lisa sends off her column. She prints out a copy of the write-up and has a final look over it to make sure she incorporated some minor changes the newsletter's editor had mentioned. She then emails the updated column to the editor. She then collects all her printouts, notes and column copy into a physical archive folder she keeps for her newsletter work. Later that day, when the newsletter is issued, she reads various pieces from it on her laptop and copies it across to her newsletter folder. That evening, Lisa also archives her electronic documents onto the external hard-drive, and deletes her backup copy of the relevant material on the pen-drive.

These snapshots express Lisa's work context, her information interaction and information relationships in greater detail than a scenario description alone. Though they largely correspond to the current computing environment, they are

abstract enough to be useful tools to explore how Lisa's information interaction may change and be facilitated in an environment that incorporates Pervasive Personal Information Spaces. Using these snapshots of Lisa's activity context, we now consider her work style and information behaviour for the current computing environment, and for Pervasive Personal Information Spaces now and in the future. At the same time we also look at some of the limitations and issues present in all these circumstances.

THE CURRENT COMPUTING ENVIRONMENT

In the current environment, Lisa has adapted to the available technology by predominantly using folders for storing documents, naming schemes to annotate documents and folders, and an information management and messaging software for keeping track of contact information and notes. She employs various synchronisation and information transfer techniques for bringing the relevant information together from different devices, and uses her memory to keep track of various information pieces and relationships.

Currently her folder set-up for her work on the newsletter includes a top-level folder called "Wines and Vineyards newsletter". This folder contains a "Submitted columns" folder for the final write-ups she has submitted, as well as a separate folder for each of the newsletters she has written for. Newsletter folders are named by date and title. After working on a column for a while, she may create separate sub-folders in the newsletter folder for storing pictures or background information, if the number of documents she uses grows too large to manage in one folder. However, some information (such as her emails from and to the web-site, and browsing history outlining her searches and findings) is generally held separately in applications or application data folders. Her browsing history, for example, further gets deleted when she clears her browser's cache and history from time to time to make space.

Lisa's email is web-based, while her bookmarks are in a separate application-based folder. She tracks certain contact information and miscellaneous notes on Microsoft Outlook on both her laptop and PDA, and other phone numbers separately on her mobile phone. She keeps her small to-do lists on paper so that she can have them on hand at all times, and those for large projects on Outlook.

In synchronising materials, Lisa copies across information she found at the library from her pen drive and backs up current work to the device as well, synchronises her PDA with her laptop to get at her notes, and copies across her pictures from the digital camera. She is in the habit of doing this on a regular basis, though time-consuming, since she could forget what she had in mind with certain notes or pictures. She also synchronises or types out any of the contacts she's called or visited for her column. Finally, she backs up her folders on the external hard-drive after a newsletter has been sent out.

Other details are more frequently kept in memory, such as her ideas for pictures she takes, segments of the articles that have items she wishes to incorporate into her write-up, the articles that discuss related topics, the location of a piece of information like the vineyard owner's contact details, as well as details from previous columns that may have an impact on the current write-up.

There are various limitations and issues present in this situation when we consider the elements of Lisa's activity. The context snapshots show Lisa's tasks of actively synchronising and transferring her information between devices, tasks that are repetitive and require time and effort. As secondary tasks, they effectively take time away from work on her main activity.

All of the contextual details in her activity, concerning people, locations, information interaction and relationships, are largely lost in her electronic information organisation. That is, her document folders can only contain this information when Lisa actively includes the information. For example, by including date information in folder names, she's actively annotating them. In the cases where the contextual detail is important, she could further copy emails related to the activity into the folder, create shortcuts to related documents in other folders, and annotate documents and information pieces with relevant notes about ideas, contacts or locations. Once again, it's up to her to actively create and manage this material.

Information does not exist in isolation. It has a context and has relationships. Lisa's current set-up does not register and associate any of these contextual details with her information work, making contextual retrieval of information difficult even though it is a natural human ability. Lisa also feels the need to explicitly create important information relationships through folder organisations and

annotations. In archiving her documents and returning to them at a later time, various information relationships and elements of the activity context would be difficult to retrace as they are largely formed and held in memory. So in the case of the vineyard owner's contact details, Lisa has to use her memory to figure out where that information could be. As she remembers the context (a previous event), she uses that information to track down documents and emails that may contain the information.

Another vital detail this look-up illustrates is the separation of information items (like emails, contacts, bookmarks, notes and documents) that have clear relationships. Consequently, even with the query lead that Lisa has, she has no single or direct way of searching for that piece of information. She has to go through her documents, written contacts and emails separately. Similarly, her bookmarks for various sites of interest to the newsletter would be in a separate folder from her column write-up unless she copies them across consciously. Retrieving previously visited bookmarks in the context of a new activity can be more laborious because their relationship to her work is missing in her information environment, effectively removing various natural cues to retrieving them.

Other limitations in the current situation relate to the mismatch between information organisation on the computer and the actual activity work that Lisa carries out. Lisa's activity consists of different, but related work, from writing emails to visiting locations and taking pictures. Information work is further personal to the user, according to the specific activity, contacts, information items (including documents and notes) and work style. The document folder reflects this entirety of Lisa's activity space and the personal side of her work only in limited fashion in its hierarchical listing of files.

Furthermore, the progress and 'story' of Lisa's work over time is also missing. The context snapshots give more of this detail and present a fuller picture of her activity. These details that form the activity story both provide a personalised work context and act as a retrieval cue to current or revisited work. In the example of the bookmarks Lisa needed to track down, the activities she used them in and the relative context they were accessed in can act as retrieval cues to help her find them within the progression of her work over time. Other documents, time visual markers or notes could for example act as retrieval cues. Each of Lisa's activities

will have its own story and together weave a complex and evolving information space that is highly personal.

Finally, in terms of returning to her column write-up on her day off, her work context of the previous session is lost. There is no easy way to remind herself of the previous work state and resume the activity. The only way to retrieve elements of her context is to search her folders for all the files and notes she handled the previous weekend. Even still, this representation is partial and requires further effort.

All of these limitations work against her goals for minimising effort in tracking and managing her work. They disrupt her work, taking time away from focusing on her main activities.

THE PERVASIVE PERSONAL INFORMATION SPACES SOLUTION

In establishing Pervasive Personal Information Spaces as far as is currently feasible, Lisa's computer and information interaction shifts towards an increased focus on her activities and a decreased emphasis on consciously managing and tracking information.

Lisa still uses folders for storing documents, however she accesses her files mostly from information space visualisations for the activity she is working on. This visualisation allows her to track all the information (e.g. documents, images, bookmarks, web-sites) she uses for the activity spatially over time, by people and/or places, by automatically monitoring her information use and adding those details to the view. Her naming schemes are less important now, as she is able to make sense of her documents from the relative chronology on her views and the context of the other items she's accessed at the same time, various types of item and activity annotations, and the contextual relationships the documents form with people and places. Many of the notes she used to store in her messaging software take the form of the annotations and symbolic markers on her view, grouped with the items they refer to.

Lisa's desktop, laptop and PDA are all part of her Pervasive Personal Information Space, giving her anytime-anywhere access to all her documents from any of these devices through the same visualisations, adapted to the device in use. For example, on returning home from the library, her PDA updates her laptop with her

notes as part of her newsletter activity. These notes are automatically grouped together with the articles she tracked down in the library.

Though Lisa still has to actively transfer items from and to secondary devices like her mobile phone and digital camera, the other devices synchronise with one another at the start and end of each session, with her laptop housing a repository of all her information items. Her pen drive and external hard-drive allow Lisa to load and store information items in one step through an archiving process that retains all her work context and annotations. (In the future, these secondary devices will also be a part of her Pervasive Personal Information Space, readily sharing information with each other.)

Several elements of Lisa's work context are registered automatically and associated with her work. These elements include her information usage, browsing activity, time and device details. Lisa can further add other contextual information to the activity, such as information sources, locations of interest or people that she collaborates with on certain documents. These details can be associated with information items or activities, so that her visualisations present more of her activity's full picture.

In retrieving information she's used within another work context, Lisa no longer needs to largely rely on her memory to track items down. The views on her information space offer different cues to locate the items because of the contextual details and information relationships presented. In retrieving bookmarks she used for a previous column write-up, Lisa for example travels back in time to when she worked on that column and locates the annotated bookmarks grouped with the write-up.

Even archived work benefits from retaining supporting details. When Lisa may have forgotten where a specific piece of information is located, she may still vaguely remember some associations or context, as in the example of the vineyard owner she wants to track down contact information for. She remembers having met her previously at a particular event. A further ability to search on various contextual details (such as a search for the event or documents accessed or received around the time of the event, across several related activities) supports Lisa in locating information beyond simply searching for files or emails.

Activity-oriented views and overviews in Lisa's Pervasive Personal Information Space allow Lisa to see the progress or 'story' of her work on various activities

over time, related to people and locations, in a way that matches her actual information interaction. They also allow her to interpret her work, discover opportunities quicker and share her information trails with others meaningfully. The activity views also allow Lisa to quickly see her work state when she returns to an activity and pick up from where she left off, as she needed to do when she returned to her column write-up on her day off. The activity spaces she creates are personalised, reflecting her work context, information behaviour and annotations.

The limitations in this initial Pervasive Personal Information Spaces solution largely stem from the exclusion of various devices, missing capabilities, and limits in the current technology.

Pervasive Personal Information Spaces provide the tools to track work, query work according to context, register or add contextual information, generate certain information relationships or form them through grouping and colour-coding. Currently Pervasive Personal Information Spaces only incorporates personal desktops, laptops and PDAs, with some special consideration for storage devices. Mobile phones, public computers, digital cameras, and all varieties of secondary devices also play a role in user activity and carry segments of the user's information space. They are however still outside of the loop at this time.

Similarly, Pervasive Personal Information Spaces tracks and brings together various information items Lisa accesses, from files and bookmarks on her device to the web-sites she visits. However, emails (e.g. emails received from web-based services) and application data (e.g. notes and contacts in Outlook) are not tracked and associated with her activity work as yet.

There are still various tasks that require Lisa's involvement in the current Pervasive Personal Information Spaces solution, even though the effort needed to synchronise information, develop an activity space and link contextual information with information items has been reduced. As many pieces of context are not easy to register automatically (e.g. the geographical location of a vineyard that Lisa bookmarked a site for, Lisa's goals for a specific activity), the user has to specify these details if they are important. Though information relationships can be generated from the proximity of access and other information behaviour, Lisa would also have to link up some information herself (e.g. the activity an item belongs in if Lisa works on different activities at the same time).

Finally, the current set-up can provide some customisation, privacy and security features. However, in tracking personal information in detail over time, privacy and security become of paramount importance, and require serious consideration. Appendix section D.1 describes a future Pervasive Personal Information Space solution that builds on the described set-up to address some of these limitations.

3.3 THE SPACES MODEL

The Spaces model is constructed from the conceptualisation of Pervasive Personal Information Spaces. Spaces is central to this research, and identifies and organises the characteristics of Pervasive Personal Information Spaces. It acts as a framework for creating integrated digital information environments in the ubiquitous computing environment. The aim is to personalise information-interaction to users, their activities and use context, to better support anytime-anywhere access to their information spaces.

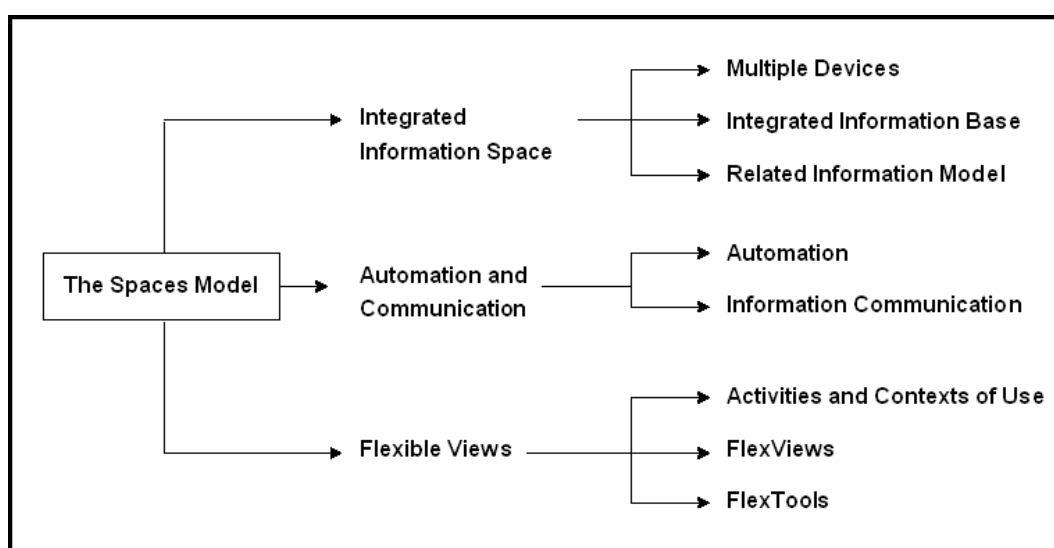


Figure 3-7: The Spaces model - Hierarchy of characteristics

The Spaces model is characterised by its

- application to multiple devices in a ubiquitous computing environment,
- use of an integrated information base,
- enforcement of a highly associative, interwoven information model,
- use of automation in information management on several levels,
- support for sharing and communicating personalised views of information between devices and between people,

- focus on high-level user activities to relate work and information items,
- registering and relating information to multiple contexts of use,
- use of flexible views on the information space, with support for multiple styles of interaction, and
- use of flexible tools to support information management and visualisation, and personalisation of all interaction and activities.

These characteristics can be organised according to the hierarchy presented in Figure 3-7 and are discussed in that order below.

3.3.1 INTEGRATED INFORMATION SPACE

In integrating a user's distributed information space, the Spaces model has to consider and support multiple computing devices, provide a shared information base and structure information according to a related information model.

MULTIPLE DEVICES

The Spaces model unifies the information held on desktops, laptops, handheld devices such as PDAs, mobile phones, and mobile storage and other digital devices such as pen drives and cameras. Potentially, this set can also include various wearable devices including smart-cards and badges, as well as intelligent site appliances. Key to supporting work on multiple devices are managing and integrating the information accessed through them, registering and tracking the different information contexts they are used in, and providing device-appropriate views of information and interaction styles.

The Spaces model works against device and information isolation. By utilising available and relevant device connectivity, the model aims to give users continuous access to their information. Consequently, inter-device communication of information needs to be timely, formatted according to user work and device requirements, and have appropriate level of detail. There needs to be support for several operating systems, types of displays, interaction styles, media and further device particulars to successfully support work with multiple devices. In summary, the following elements require consideration:

- multiple device support (multiple operating systems, interaction styles, screen areas and resolution),
- device connectivity (intermittent and continuous, wireless and wired networks),

- inter-device communication protocols and management, and
- device-based information access, views and exchanges.

AN INTEGRATED INFORMATION BASE

At the centre of the Spaces model is a large information base or repository, which collects and relates all information items from an individual's use of different computing devices to other items, users and use contexts. Consequently, the information base will consist of information items and documents, details on information objects (including users, contexts, activities and views), details on use contexts and information relationships (e.g. between activities, items, and information objects), as well as user settings and preferences. The information base is centrally stored on a device of choice, and is otherwise kept flexible and complete. Information within the repository is shared between devices as required by the user's work and according to the type of devices in use.

RELATED INFORMATION MODEL

The Spaces model sets up a personalised, associative structure of information where information objects (information items, users, devices, locations, contacts, goals, activities, views, view annotations and so on) are all first class citizens. In this world of personal information, instances of these objects have a distinct identity.

Information objects have properties, purpose, relationships with one another, as well as preference and option settings (w.r.t. security, privacy and viewing for example). These properties are derived from information items and documents themselves (e.g. standard file details and author details), their use (e.g. use and information contexts, information sources, user activities, devices and physical locations), and user specified information (e.g. keywords, tags, categories, goals, spatial arrangements and grouping, symbols and signs, annotations, settings and views).

Existing tools utilise this set-up to some extent. The Windows OS for instance supports keyword and category specifications, and thumbnail views of information. Newer developments such as Presto / Placeless Documents (Dourish *et al.* 1999 and 2000) go further and allow items to be stored, retrieved and managed according to personal and universal properties.

Within the Spaces model, information identity allows users and objects to interact, share and communicate appropriately with each other. Their identity further gives details on how they can be accessed and viewed (e.g. appropriate views, preferred devices and interaction styles), how they and their related views can be manipulated and which relationships and contextual associations they can form.

3.3.2 AUTOMATION AND COMMUNICATION

Automated processes, inter-device and inter-person communication play an important role in the Spaces model in minimising user effort, tracking and communicating user work, and providing anytime-anywhere access to information appropriately.

AUTOMATION

Many functions within the Spaces model are automated (or can be automated according to the user's preferences). The Spaces model uses of a variety of agents to perform these functions. These functions include:

- Integrating and managing information from different devices: Collecting information from the user's various devices and setting up the collection as a shared information repository on one device. The complete information repository as well as the local device repository is automatically managed, structured with the appropriate information relationships, updated and shared according to user activity on the devices.
- Monitoring information and file use: Tracking documents accessed by the user, user browsing trails, annotations, phone calls and messages. Including these details into the user's integrated information base as well as updating any current views with this information.
- Registering and tracking context: Registering details about the user, device in use, location of use, time, user activity, people involved and other relevant contextual details where possible. These are also incorporated into the information repository and appropriate information relationships.
- Formatting and adapting information to match devices and user contexts: Adapting information items and their content, views and view content according to the user's work, user security and privacy settings, and device capabilities and limitations.

- Archiving, storing and categorising information: Semi-automated processes for archiving the information repository in part or entirely, and storing and categorising information according to user preferences. Users can access archived information at any stage according to their original information hierarchy, use contexts, activities and views, as information objects in the repository are stored and archived with all their structure, content, associated views and relationship details intact. Some application intelligence can be developed for categorising and clustering information for views, recognising current user activity in multi-activity sessions, and determining user contexts (e.g. location, device and social context).

INFORMATION SHARING AND COMMUNICATION

The Spaces model seeks to improve the way users synchronise work carried out on multiple devices (to facilitate individual work) as well as share work with others (to facilitate social navigation and elements of group work). Consequently, a requisite of the model is effective inter-device and inter-personal information access, sharing and communication. In managing inter-device communication and inter-personal information sharing, the model deals with device connectivity, device and user identities, user privacy and security settings, access controls, communication protocols, information formatting and completeness, for transferring information appropriately.

Synchronising information between devices involves sharing and updating information between devices and the information repository according to user work, use context, device capabilities and device sessions. Synchronisations can be continuous, session-based or user-activated according to the application. Generally, communication of information involves the transfer of entire information objects and the relevant information structure and relationships. Within the Spaces model, devices no longer purely deal with transferring small sets of documents or some details on settings, but will rather be increasingly involved with transferring complete (personalised) views on information and corresponding items from the underlying information collection alongside privacy, view and interaction settings.

According to where and to whom the information is transferred, device restrictions or access privileges might require information to be transferred in

limited form or as a summary. Security and privacy play an important role to keep user information secure when transferred between devices and to protect personal and sensitive information, and can make use of device and user identities. Access control settings can allow users to limit how the information they share can be viewed or manipulated. Users can share views in part or entirety and work together on activities, or simply share information trails without giving access to the actual underlying information items.

3.3.3 FLEXIBLE VIEWS

At the core of the Spaces model is the Flexible Views paradigm, which follows the user-subjective design principles presented by Bergman *et al.* (2003) discussed before. Flexible views emphasise user activities and contexts of use and provide flexibility through versatile tools (FlexTools), which help users tailor views on the information space to their individual work.

ACTIVITIES AND USE CONTEXTS

User's work and information use is predominantly organised and viewed within the context of their high-level activities within the Spaces model. Activities are high-level areas of interest or work. They have associated goals, are user-specified and unique to individuals. Because they change and evolve over time, an information space segmented according to user activities is highly personalised and provides much insight into the state and development of a single user's work and interests. Activities can further be related to each other and to use contexts, such as specific devices, locations, user groups or (recurrent) time periods.

Within the Spaces model, all information used by the user is automatically associated with one or more activities within the information space. The model uses activities as the basis for all the views it provides and can further automatically store information items in a hierarchical arrangement according to these activities. Viewing information according to activity allows users to more readily focus on the task at hand and simplifies the process of task switching.

Individuals' work is further done within a context. As discussed in section 3.2.1 on *contexts in information work*, this context of use changes according to the people involved, activities undertaken, information accessed and manipulated, locations of use, time frames, user goals and tasks, and devices and applications

used. Activities are themselves one type of work context, and probably the most significant one in the Spaces model.

One of the aims of the Spaces model is to provide contextual access and visualisation of information to users to facilitate their everyday interaction and use of their personal information space. Users can alter the views on the information space according to various contexts to suit their needs. Views on the information space can for instance be limited to a select number of activities, within a specific time frame and accessed through one particular device, or any other such combination.

The Spaces model must allow devices to automatically register or ask for contextual information to completely support this. Contextual information that is gathered has to answer the questions of who (social), what (activity), which (information or knowledge), where (location and environment), when (temporal), why (goals) and how (device and computing technology) of information used by an individual. The Spaces model can then relate these details to one another and help create flexible, rich, associative views of the information space.

FLEXVIEWS

As mentioned, flexible views (FlexViews) are a key aspect of the Spaces model and form the central interface to the user's information space. Views are kept flexible to provide information visualisation and access tailored to user activities, goals and varying work contexts, as well as to support users in naturally interpreting their information space and computer-supported work across personal devices. Accordingly, FlexViews aim to minimise effort on the user's part to organise information at a lower level and seek to minimise the intrusion of information management tasks on high-level user activities.

Moving away from standard, single views on the information space (through hierarchies or spatial arrangements), FlexViews allow users to change their views on the information space according to the contexts of use (e.g. device, location, time cycles, people, activities and goals as mentioned previously) as well as visualisation styles (e.g. linear, map, hierarchical, spatial, temporal and network). By further allowing users to change the amount of detail they see on the display, adapting and formatting the view and view contents to the device in use, and supporting different types of views, the Spaces model adds to view flexibility.

FlexViews provide rich, associative content, besides the customisation according to contexts and visualisation styles. View workspaces can represent information relationships by supporting thumbnail references to information items, visual cues matching document details such as size and importance, item clustering, colour-coding, annotations, action markers, simple workspace diagramming tools and activity progress indicators.

FlexViews include single and multiple views, combination views and overviews, and standard and pre-set contextual views. Multiple views allow users to have several independent FlexViews on the information space visible at the same time, as opposed to single views, which largely support continuous work in one area of interest. All FlexViews can be combination views, i.e. views on the information space that are shaped according to several selected contexts and visualisation styles. Overviews are created when the views are set up to provide information about a large segment of the information space or the information space in entirety. Finally, standard and pre-set contextual views are provided as a starting place for common activities. A separate set of tools, namely FlexTools, allows users to manipulate the views within the Spaces model.

The various types of FlexViews have a further adaptive quality. Though the underlying information space stays the same, the views and view-set would vary with the user's personal devices, according to the device capabilities, screen size and available interaction styles. Smaller mobile devices with limited screen real estate and capabilities may have a limited, simpler set of views compared to devices like desktops and laptops. The fundamental look and feel of FlexViews however stays similar on all devices to keep information access and interaction familiar.

Implicit in the goal of managing information accessed on multiple devices is the support of multiple styles of interaction (e.g. keyboard and mouse, stylus, keypad, voice and gesture input, multi-media output and different size displays). The richness of visualising information using FlexViews can be advantageously supplemented by further richness in interaction. Direct manipulation using keyboard, mouse or stylus is used in the views to select items, move objects on workspaces (e.g. information item references, icons and symbols, notes), navigate views using pan and zoom functionalities, perform incremental queries and so on. Agents are further used for automatically monitoring and registering information

use and contexts, and creating a certain level of interface intelligence. Customisation and personalisation settings are further used to adapt views to the individual's visual and interaction preferences. Finally, user differences and preferences can also be supported by multi-modal input and output, which can be extended at a later stage to include audio and speech (e.g. voice notes, speech-based access to views and information items, and audio 'sweepers' to indicate information landscape and broad content).

FlexViews supports user work in a variety of ways by providing rich, annotated views of the user's information space and keeping track of user information trails by presenting details according to high-level activities and use contexts. Users can work with views that are uniquely shaped to them and their activity, interpret their work progress and changing information space, archive information with all these information relationships intact, revisit past activities without missing details of the work context, easily switch between and resume activities across devices, and share their annotated information trails with others.

FlexViews act as a lifelong information companion, providing an annotated, pictorial log or detailed visual diary of the user's computer supported activity, linking information and activities with people, time, events, locations, devices and goals. Information management recedes into the background, while information activity, interaction, experience and discovery take centre stage.

FLEXTOOLS

Automation, a related information model and flexible views support information management, access and visualisation to a great degree. Further support within the Spaces model is provided by a set of versatile tools collectively called FlexTools. Firstly, these tools allow users to manipulate views and view content on the information space; change automation, privacy and security settings; and create and amend relationships between information objects within their information space. Secondly, FlexTools also provide support through filter and query tools, options for changing the level of detail in a view, options for archiving and sharing information as well as tools for creating annotations, placing symbols and icons on the workspace, personalising the environment, and providing goal/task information. The following list gives descriptions of these areas of support:

- Views: Creating views, selecting or changing a view to a view type, such as single and multiple views, and standard and pre-set contextual views.
- Information objects or contexts: Creating and updating information objects such as activities, contacts, devices and locations.
- Activities: Creating and selecting activities, as well as listing and selecting views, contacts, queries and so on according to specific activities.
- Contexts: Selecting specific contexts, alone or in combination, to limit the view on the information space. Selections are based on the user's devices, locations, time frames, people, activities, goals, information relationships and sources.
- Visualisation / presentation styles: Selecting specific styles, alone or in combination, to alter the view on the information space. Selections can be made from spatial (linear or map), hierarchy, temporal and network styles of visualisation. Various options can also be selected for the styles, such as timeline granularity or map type.
- View details: Viewing the information space at different levels of detail, e.g. with only title information, using thumbnails and titles, or with visual cues indicating relative file sizes, use and priority information.
- Goals, tasks and behaviour: Viewing, adding and amending goal and task information and relationships, as well as tracking information behaviour (e.g. displaying changing emphasis in the user's information space and activities, and visualising frequency of work, activity levels and progress).
- Relationships: Viewing and amending relationships between information objects, e.g. relationships between information items, activities and goals, and information items and information sources.
- Filters and query options: Selectively filtering out segments of the view or querying segments of the information space according to specific criteria (including contextual information), as well as viewing query results as lists or views with a contextual frame of reference for the given results.
- Annotations: Creating information item annotations, adding workspace notes or view notes, placing icons and symbols (e.g. notes, action markers, signs) on the workspace, adding simple workspace diagrams, as well as options to provide context and activity details.
- Automation, information use and context monitoring: Altering settings for automation (e.g. with registering context, categorising information, or adapting

views to devices) and the way the system monitors information use (e.g. the information items and sources registered, switching monitoring on or off).

- **Personal settings:** Setting and altering user preferences for personalising and customising the system (e.g. changing display fonts and colours), and settings for privacy (e.g. setting visibility of user information), security (e.g. updating user details, providing user identification and selecting encryption options), view and interaction (e.g. view appearance and preferred interaction style), and access control (e.g. setting access rights for shared information according to user contacts).
- **Archiving:** Archiving and retrieving archives of the entire information repository or segments of it, with supporting details like information relationships, views, annotations and settings.
- **Sharing views:** Sharing activity details and information foraging trails by sharing views or view segments with annotations, contextual information and potentially the underlying information items in support of social navigation, as well as utilising multi-user views on the shared information space when collaborating on activities.

In summary, with an integrated information space, an activity and context-based focus, flexible views and the versatile tools offered, the Spaces model seeks to achieve visualisation, interaction and access of information that is highly personal, ubiquitous, subjective and context-sensitive in nature.

An integrated personal information space that largely structures and integrates itself shifts the user focus from information management and synchronisation towards carrying out their activities anytime-anywhere in the ubiquitous computing environment, without losing their work context.

An activity-based view on the information space allows users to work and access their information according to the high-level activities and interests that are unique to them, and naturally support activity-continuity. For each individual, activities and types of activities in progress vary, as well as which activities are recurrent and which are carried out concurrently. Furthermore, there is a changing emphasis of activities over time within each individual's information space. As such an activity-based view can provide much implicit information on the current

state of an individual's activities, the shift in focus or interest, progress of activities, personal evolution and activity-related behaviour.

Within the Spaces model, information use is monitored and registered alongside contextual information. Accordingly, information items are associated with this contextual information, i.e. with other information items, activities, devices, locations, people and so on. Using this information, flexible views allow users to perform a context-based shift on the information space, gearing it for example towards a particular device, a group of people, a specific goal or set of activities. As views can be saved, individuals can create various interfaces to their information space that is uniquely suited to their activities, devices and work styles. Making sense of documents and work context can become more implicit and natural.

Further tools and settings assist users with annotating their information space, classifying and assigning priority markers to items, adjusting privacy and security settings to support appropriate sharing of information, setting their preferred viewing and interaction modes, as well as tracking their progress and information behaviour.

Together the Spaces model's characteristics help develop Pervasive Information Spaces that are a constant companion to users moving through their information space, connecting the virtual world with the real world. With FlexViews, the user's entire information or activity space is re-created around them, continuously available, with rich associative detail.

As the goals for the Spaces model are ambitious, the scope for this research is limited by time and to some extent technology. It is furthermore also limited to the user domain of 'personal distributed electronic information spaces' as detailed in section 3.2.1. Consequently, the model characteristics are investigated within these boundaries through the InfoMesh system, an example implementation of Pervasive Personal Information Spaces.

3.4 FUNCTIONAL REQUIREMENTS

The functional requirements for InfoMesh, as also the non-functional requirements, are drawn from the characteristics of the Spaces model and limited to the research scope and user domain. While the Spaces model gives a broad

picture of what is desirable of Pervasive Personal Information Spaces in the real world, the functional requirements are more specific. These requirements form the basic building blocks for an initial system and can be extended over time to achieve the goals explored in the model more fully.

3.4.1 INTEGRATED PERSONAL INFORMATION SPACES

Requirements for creating an integrated personal information space through InfoMesh focus on working with multiple devices, creating an integrated information base and applying a related information model to structure the user's information space and its attributes.

MULTIPLE DEVICES AND AN INTEGRATED INFORMATION BASE

- (a) InfoMesh will focus on desktops, laptops and PDAs. Smart phones, mobile phones, other digital and storage devices will not be designed for at this stage.
- (b) InfoMesh's information base needs to include all information items and related details stored and accessed on the user's devices (pertaining to the folders specified by the user). The details and contents of the user's entire information collection will be integrated and managed centrally on the user's specified main device, with secondary devices exchanging information with this information repository as needed.
- (c) The information base will structure all the details of the user's information space as specified by InfoMesh's related information model. Consequently, the repository will contain various information items (e.g. documents, pictures and sound clips), and flexibly relate these to one another, item details like annotations, contextual information (devices, time, locations, contacts and so on), activities, views and sessions. The information base will also contain details about the user and their settings for privacy, security, access control and system preferences. At present InfoMesh will support most standard information media, except for email or items such as calendar-based meetings, reminders and tasks/goals managed by applications like Microsoft Outlook.
- (d) As mentioned before, the information repository will be managed by InfoMesh on the main device. All information updates received from user activity on secondary devices will be added to this repository. Information will be saved to the user's information collection after each update. Updates would

include changes to documents, work contexts, devices, activities, views, settings and information relationships. Secondary devices will only hold a segment of the information base in their local storage, specifically the segment that is required to support the user's work context.

RELATED INFORMATION MODEL

- (e) InfoMesh needs to use a related information model to structure the user's distributed information space. This model will need to hold details and relationships of a variety of information objects, namely the user, user settings and preferences, information items, information sources, views as well as contextual objects (specifically activities, devices, contacts, locations, time frames, goals and tasks).
- (f) In InfoMesh all information objects need to be first class citizens with a distinct identity as described by their properties, purpose, settings and relationships. For information items such as documents and images, properties will be derived from their file details, their usage (e.g. contextual information), and user specified information (e.g. keywords, annotations, colour coding, activity associations).
- (g) InfoMesh will exchange information between devices as information objects, with their contents and relationships intact. Similarly, backups of the information collection carried out by InfoMesh will include the entire information structure, its objects and their relationships.
- (h) In the related information model, information items can relate to any one or more of the contexts (i.e. instances of the contextual objects such as activities, devices and contacts). The same information item can relate to many different instances of an object (e.g. a document can be part of several activities). Furthermore, any of the contexts or combination of contexts (e.g. activity and time, or devices and locations) can potentially have an associated view, which would display the information according the context(s) chosen. InfoMesh will only need to support a selection of practical context combinations.

3.4.2 AUTOMATION AND COMMUNICATION

Requirements for automation and communication in InfoMesh deal with automated processes such as monitoring and registering information usage as well as inter-device and inter-personal exchange of information.

AUTOMATION

- (a) InfoMesh needs to automatically monitor the user's information usage on his/her devices according to user specifications (e.g. My Documents folder, web browsing, and bookmarks) and automatically populate views on the user's information space with these details.
- (b) InfoMesh also needs to register and track the user's different information and work contexts by recording or using user-specified information about the user, time, activities, information and workspace annotations, devices, locations, communications and the like. These will be updated to InfoMesh's information repository.
- (c) InfoMesh will further also record and update the user-created contextual web of communicated and shared information (through email, messages, notes and reminders) to the information repository where possible.
- (d) InfoMesh has to format and adapt information appropriately for the device in use to match both device capabilities and the user work context.
- (e) InfoMesh needs to offer an automated back-up feature for creating regular backups of the information repository (including structure details, item attributes, contextual details and relationships). Users can specify the frequency of backups performed.
- (f) Certain further tasks need to be automated by the system and carried out behind the scenes, such as integrating information from multiple devices, updating and maintaining local and main information repositories, managing inter-device communication and synchronising information between devices.

COMMUNICATION

- (g) InfoMesh will use a session-based synchronisation approach. Desktop and laptop devices will exchange information across a wired or wireless network at the start and end of each device session. PDAs will exchange information on synchronisation with one of the user's devices at this point in time.

- (h) Inter-device communication for running InfoMesh would involve devices sending updated details on the information space structure and information relationships (including for example activity details, new and altered views), updated documents, changed user settings (e.g. privacy, security and preferences settings), as well as information item details including annotations and contextual attributes. The information exchange also needs to be targeted to the device, so that device appropriate information detail can be sent (for example, a PDA does not need to receive all updated documents or document summaries, only those the user requires).
- (i) InfoMesh's protocols for inter-device communication and information exchange should include verifying that both devices belong to the same user or user account. The communications also need to use appropriate privacy and security measures to protect the data sent to other devices or shared with other users.

3.4.3 FLEXIBLE VIEWS

The flexible views paradigm in InfoMesh uses context-based, flexible views for information management, visualisation, access, interpretation, retrieval and synchronisation. Requirements for implementing the flexible views paradigm focus on a variety of features including information structured around user activities and use contexts, flexible views (FlexViews), and lastly, versatile tools to manipulate the views, personalise InfoMesh and manage information (FlexTools).

ACTIVITIES AND USE CONTEXTS

- (a) InfoMesh needs to manage and present details in the user's information collection according to the user's activities and contexts of use.
- (b) Activities in InfoMesh are user-specified high-level areas of interest or work, have associated goals and are carried out within various information contexts. They have all the properties they do in the real world. Information items can belong in more than one activity and / or context. InfoMesh needs to track certain pieces of information outside of any specific activity as necessary.
- (c) Use contexts of importance in InfoMesh will be the activity, information, social, physical (location-environment), temporal, goal and computing / device

contexts. These contexts will answer the who, what, where, which, when, why and how of the user's work context.

- (d) InfoMesh needs to automatically track information about the user, time of use, the device in use, the information created or accessed, and information sources where possible. Other contextual information such as activities (e.g. detailing new and current activity), goals, locations (e.g. work, home) and social context (e.g. group members) will need to be specified by the user at this stage of implementation. The degree to which users supply these details and other information via annotations and workspace markers will vary with each individual. This will dictate the thoroughness of the relationships between contexts, activities and information items that InfoMesh develops in its information repository.

FLEXVIEWS

- (e) InfoMesh has to provide views that are flexible, by providing visualisations of the underlying information collection that can be filtered by various user-specified combinations of activities and use contexts. This can help users create personalised views with content that is adjustable to changing work contexts. The initial views provided by InfoMesh will mainly focus on activities in combination with specific contexts, particularly time, location (maps), people and devices.
- (f) InfoMesh will start off by supporting several types of combination views, namely several work views and pre-set contextual views. These will include a work view and an overview of the information space, activity views that provide chronological activity workspaces, map-oriented activity views and social network views.
- (g) Views in InfoMesh need to further provide rich, associative content to represent information relationships in the user's integrated information space. Consequently, view workspaces will be supporting the following items and features: references to information items; thumbnails of information items and views where appropriate; item details (e.g. title, time, type, source and author); item visual cues (e.g. thickness, shape and size based on importance or frequency of use); item clustering, arrangement and colour-coding; item and workspace annotations, notes and action markers; workspace pan and zoom

functionality; single-click access to item content; context menus for manipulating and annotating workspace items; representation of progress and activity levels; and simple diagramming tools to further annotate the workspace.

- (h) InfoMesh views will need to highlight information relationships in the following ways: information items are related to the underlying activity or activities and contexts represented by the view, items are related to each other by grouping and colour coding, and items are related by visual cues and markers (including notes and messages, reminders, priority or action markers, and keywords). Item relationships to contexts include an item being part of one or several activities, related to a goal, authored or shared with or by another contact, preferentially bound to a particular place or device, or related to an event or time-frame.
- (i) InfoMesh needs to further support information behaviour through flexible views in several ways. Firstly, users should be able to share their information trail by sharing their views with others, as images or as interactive views, with or without underlying information items. InfoMesh can allow users to send these views as attachments to their contacts. Secondly, InfoMesh has to support archiving sections of the information space or the information collection in entirety (with all the activity and contextual details intact) for later retrieval. This way, the user will always have access to their activity and action history with the pictorial contextual depiction of their work. Finally, the views have to be kept synchronised across devices with the user's work context intact, for easy task switching and task resumption.
- (j) Flexible views need to be optimised within the scope constraints to support interpretation of the information space in a variety of ways. The views would need to display changes in and direction of user interest and learning by presenting information access and foraging trails. The views should help users with interpreting the state and progress of their work, and understand relationships between activities by providing overviews of activities and activity levels. Finally, InfoMesh will need to give users a natural way of accessing, remembering and retrieving information as well as a natural way of resuming activity, by offering activity and context-based access and retrieval of items and item related details.

- (k) InfoMesh has to provide device-appropriate information and visualisations with FlexViews. Views, view content and detail, information item detail as well as information access need to be adapted to devices according to device use, device context, display screen and interaction style capabilities. InfoMesh will provide detailed versions of standard views for laptops and desktops and simpler versions for PDAs, with interaction through keyboard, mouse and stylus.

FLEXTOOLS

- (l) InfoMesh will provide versatile tools (FlexTools) for customising, querying and visualising views as well as for adapting InfoMesh processes and settings to suit the user. These tools have to be provided as toolbars or panels that allow users to change InfoMesh and its views on the fly.
- (m) FlexTools needs to provide options for creating activities and views, as well as new concurrent views based on the current view or activity. There also need to be options for creating new context instances and updating existing ones (e.g. contacts Steve and Dave, and devices laptop, work desktop and PDA), as well as adding new devices to the user's InfoMesh and editing these. A folder-like browser can be further considered for providing access to activities and their views, as well as additionally displaying the content as a listing.
- (n) FlexTools has to provide options for querying the information space and its views at various levels of granularity, taking into account different contexts and activities, devices, information items, information sources, as well as annotations, workspace notes and markers. Query results can be returned as lists, or as visual segments of the corresponding activities and views so that a context can be provided for the results.
- (o) Users should also be able to filter views or the information space for specific information to match a scenario, according to selected terms, file use and frequency, and specific period of time. Filter options in FlexTools need to be incremental, where one filter can be applied on top of the other.
- (p) In line with the filter options, FlexTools should also provide users with options to select and vary the contexts that underlie the view content, and list the contexts that inform the current view. The initial emphasis on contexts will be on activities, devices, people and time frames.

- (q) Furthermore, FlexTools also has to offer options for manipulating the visualisation or presentation styles of the current views. Preliminary selections offered will be restricted to select hierarchical, spatial (linear, map or standard workspace), temporal and network styles of visualisation.
- (r) FlexTools needs to allow users to change the level of detail presented on view workspaces, by providing options to view or hide thumbnails, title and information item details, and item-oriented visual markers. There also needs to be a way for users to denote important documents within the activity or view, and have easy access to these.
- (s) InfoMesh will further offer users tools for adding annotations to their activities, views and information items, as well as for supplying contextual details for information items. These tools should also include drawing tools and a selection of symbols and action markers for users to annotate the workspace with various notes, icons to indicate importance or action, and simple diagrams to signify relationships.
- (t) FlexTools also has to provide an array of options for changing InfoMesh process and automation, display and security settings. There need to be options for sharing views (for sharing information foraging trails and annotated view content with contextual details) and archiving segments of the information space (with information relationships and contextual details intact). Users need to be able to modify InfoMesh's synchronisation, information usage monitoring and contextual information registration settings, for example in case the user wants to switch monitoring on or off, or only wants specific information or work tracked, registered and kept as a persistent part of the information space.
- (u) FlexTools has to provide options for manipulating InfoMesh view display settings and preferences. These can relate to timeline granularity, display of activity levels/progress and visualising frequency of work, workspace placement of information items, amount of view pockets presented in the workspace, and options for changing InfoMesh colours and fonts.
- (v) Finally, InfoMesh will need to offer options for managing privacy, security and access through FlexTools. These will allow devices to be identified as belonging to the user before giving access to or exchanging information, and allow the exchanged information to be encrypted to a degree and users to

share views with colleagues, team members or friends with full or limited functionality.

3.5 NON-FUNCTIONAL REQUIREMENTS

The non-functional requirements for InfoMesh focus on quality issues and constraints to system functionality and implementation. They are categorised according to requirements relating to user interface and human factors, design and implementation, resources and performance, and quality issues.

3.5.1 USER INTERFACE AND HUMAN FACTORS

- (a) As a supportive tool allowing users to naturally work according to their activities and work context, InfoMesh should be non-invasive and non-distracting, and increasingly transparent.
- (b) InfoMesh further needs to be readily learnable and usable through recognisable visible metaphors for viewing and manipulating information, such as timelines, thumbnails, maps, markers and sliders for filtering the views. Easy navigation methods as well as using existing familiar techniques for choosing options and interacting with the interface are also of importance.
- (c) InfoMesh will provide ample help information within the system, including feature and task-oriented help. User documentation for InfoMesh will need to include a user manual, with a variety of examples and activity snaps to help orient the user and support exploration of the interface.
- (d) The system also needs to keep users updated and informed with appropriate messages or visual feedback to for example indicate when synchronisation is occurring, which information is transferred, when views are altered or shared and so on.
- (e) Finally, InfoMesh has to allow users to customise and personalise the interface and have control over how the system manages their personal information space and contents, including how the views look, when work gets tracked, and which pieces of information are registered. These details have been covered earlier on, as FlexTools is meant to largely support these tasks.
- (f) Similarly, as mentioned before, InfoMesh has to flexibly support several interaction styles (e.g. mouse, keyboard and stylus), different work contexts

and activities, and various perspectives on the information space according to the user's individual preferences.

3.5.2 DESIGN AND IMPLEMENTATION CONSTRAINTS

- (a) Within the ubiquitous computing scene, there are multiple platforms to consider and various constraints according to the devices used. InfoMesh will start off by supporting a maximum of 5 user devices running on Windows XP (desktops and laptops) or Pocket PC 2003/Windows Mobile 5 (PDAs) operating systems.
- (b) InfoMesh will have an initial limit on the size of the information collection it can manage. The limit will be set to approximately 25000 files across the devices, all together under 5 GB in size. The system should be designed to manage the user's growing personal information space over a number of years.
- (c) When sending updated documents between devices, InfoMesh will initially only transfer files under 10 MB in size to keep session-based synchronisation times reasonable.
- (d) InfoMesh needs to be kept extensible, and scalable both horizontally and vertically. Consequently, InfoMesh design should support this. Analysis and design documents as well as hardware documentation will be generated for easy maintenance and updating of InfoMesh.
- (e) The system will need to monitor and register information and information usage according to the constraints of the operating system, programming environment and related security features. For example, in Windows XP, InfoMesh will not be able to monitor accessed files with the same accuracy as created or modified files.
- (f) InfoMesh's physical environment will be wide-ranging, as certain personal devices are mobile. The user's devices may be continuously or intermittently connected via a wired or wireless network. Initially, InfoMesh will function using a session-based synchronisation. An assumption is made that multiple devices are not used simultaneously and that a relatively high-speed connection is always available for information exchange among devices at the end of sessions.

- (g) Furthermore, InfoMesh will have to update information to different devices according to the level of importance of the information, the device capabilities, and the user's information use context. Information may be transmitted in its entirety, as a summary or as a segment. Of importance here is that PDAs often convert certain document types, whereby selected formatting details are lost in the conversion process.

3.5.3 RESOURCES AND PERFORMANCE ISSUES

- (a) As InfoMesh will be dealing with large amounts of data, the system should minimise the amount of memory taken up for storage of internal information.
- (b) Automated backups provided by InfoMesh should store details from the information repository on external storage or other devices to prevent loss of data. On restoring backups, InfoMesh should be able to retrieve the original information repository structure and contents, allowing all of the user's annotated views to be fully reconstructed.
- (c) As InfoMesh is meant to heavily support personal information management across devices over long periods of time, the system needs to be robust and reliable to prevent data loss and inconvenience in carrying out work. The initial prototype should be able to manage a couple of weeks of continuous work without serious failures to allow adequate testing of InfoMesh concepts.
- (d) InfoMesh will interface with existing software applications and the underlying folder system of information items, without interfering in their processes or hindering their customary use by users.
- (e) InfoMesh provides many automated tasks and has to perform these operations efficiently within a reasonable time frame. These operations include storing and loading information from the information repository; creating, presenting and manipulating views on the information space at the request of the user; and synchronising information between devices.
- (f) Furthermore, InfoMesh also has to provide realistic response times, especially with user-triggered changes to the views on the information space. For example, creating views, querying or filtering the information space, as well as changing the contexts, view detail or visualisation style of the views, should

provide visual feedback and responses from the system within reasonable time limits.

3.5.4 QUALITY ISSUES

- (a) InfoMesh needs to focus on minimising faults and applying effective error handling, allowing the system to recover easily from errors. Fatal errors in a system like InfoMesh that aims to support and track continuous activity can hamper its use and usefulness greatly.
- (b) Error messages in InfoMesh need to be clear with easy alternative options for users to recover from the error or backtrack to a previous state.
- (c) InfoMesh needs to save changes made to the system and the information repository after each change to limit loss of data. A few levels of un-do and re-do options need to be provided to users as well, so that they can readily return to a previous state of the interface or compare different versions of the views.
- (d) InfoMesh is designed to manage a single individual's personal information space and will use a form of user identification for granting access to the system and the detailed information repository. As information transmitted between user devices can be quite personal and sensitive, transmissions have to be encrypted for security.
- (e) Users can share views or view segments with other users. Consequently, InfoMesh should provide a selection of privacy, security and access control options to manage the level of access another may have of a shared view. For example, views may be encrypted when sent, and access may be limited to the view presentation only, or to part of the underlying documents or all of the underlying documents and so on.

3.6 SUMMARY

Pervasive Personal Information Spaces allow users to work on multiple devices, in different locations, in varied contexts of use, while viewing and accessing their entire, integrated information space through activity and context-oriented, highly personalised views.

The concepts in Pervasive Personal Information Spaces centre around personal information spaces and this domain's characteristics, high-level user activities and

the user-subjective view on information spaces that they provide, and contexts in information work. Early on, this chapter provided an exploration and exposition of contexts in information work that can benefit in the design of visualisations and interaction for accessing electronic information collections. These contexts focus on social (who), activity (what), information (which), physical (where), temporal (when), goal (why), and device (how) aspects.

Characteristics of Pervasive Personal Information Spaces were next modelled in Spaces, a framework for developing Pervasive Information Spaces for a wide variety of electronic information domains and more specifically for the domain of personal information spaces. Broadly, the model's characteristics focus on integrating information spaces across devices and relating them meaningfully, automating information tracking and transfer, and providing flexible views on the information space according to user activities and work context.

In proposing the Spaces model, the thesis sought to address the limitations of prior work exposed in chapter 2 by:

- Proposing and incorporating the seven contexts that capture user-subjective details of the user's information interaction. These can assist in creating meaningful, associative models of user information for supporting information work.
- Emphasising user goals, activities and contexts, over simply information management or knowledge access, to relate all information and information-interaction back to the user and their work.
- Integrating information automatically from multiple personal devices to overcome information fragmentation, offer anytime-anywhere computing, and support activity work and continuity.
- Providing multiple contextual, flexible views with versatile tools to support personalised ubiquitous information-interaction. These views also offer multiple, visual perspectives on the information space to more naturally support contextual and associative information access, interpretation and retrieval, as well as other information behaviour.

Due to time and technology constraints, the research scope was limited to the elemental characteristics of the Spaces model and the domain of users' personal distributed information spaces.

This chapter lastly listed the functional and non-functional requirements that were specified for InfoMesh (an example implementation of Pervasive Personal Information Spaces) focussing on the model characteristics as well as quality issues and system constraints. The next chapter presents the interface and interaction designs for InfoMesh that were guided by these requirements.

CHAPTER 4 - DESIGN

INTERFACE AND INTERACTION DESIGN

4.1 INTRODUCTION

This fourth chapter first presents the interface and interaction designs drawn up for InfoMesh from the functional and non-functional requirements listed previously. The section also details the design approach, design space and design rationale. The InfoMesh designs consider the essential visual components of the InfoMesh desktop and PDA interfaces (through views, view content and view tools), alongside the employed modes of interaction. The design space mapped out by the underlying designs, design elements and choices forms the visible embodiment and exploration of context-based flexible views that lie at the heart of Pervasive Personal Information Spaces.

The chapter then reports on the main design tools that informed the interface and interaction design of InfoMesh, namely personas, scenarios and activity snaps. Activity snaps were developed as part of this research for incorporating realistic activity data into designs and prototypes to drive conceptual and physical design as well as to help evaluate and refine design elements and functionality. As such they have shown much promise as a design tool for use alongside personas and scenarios in the development of information-rich, interactive systems. The personas, scenarios and activity snaps (PSA) life cycle is subsequently summarised to provide guidelines for their combined use through the various system development phases.

4.2 INTERFACE AND INTERACTION DESIGN

Interface and interaction designs for InfoMesh aim to support flexible and context-appropriate, visualisation and access to the user's distributed information space within the given research scope. The formulated requirements based on the Spaces model as well as worked out personas, scenarios and activity snaps (described in the following section 4.3) helped guide these designs.

This section first describes the process followed in designing the InfoMesh user interface and interaction, with details about the design and design evaluation approach and mapping out the design space. The section then explains how InfoMesh would represent an information space using views, and presents and discusses various InfoMesh interface and interaction designs for desktops and PDAs. The designs for InfoMesh have to take a range of interaction and

presentation styles, features, tools and devices into consideration. Primary design areas focus on the presentation of the information space through flexible views, the interaction suited to different views and devices, the tools to support natural access to information and view flexibility, and general information management support for users. The section concludes with a brief discussion on the design rationale and the InfoMesh design space.

4.2.1 THE DESIGN PROCESS

The process for designing the interface and interaction for InfoMesh involved planning out a design approach, thinking about the design evaluation options, and mapping out the design space at both an abstract level and through the designs themselves. Also of importance was recording and reviewing the design rationale, while keeping the research objectives, previous research, user experience goals, design alternatives, and evaluation findings in mind.

DESIGN AND DESIGN EVALUATION APPROACH

The Pervasive Personal Information Spaces concept and model showed the need for a tight integration of functionality and interface design in InfoMesh. InfoMesh design basics would first be derived from the requirements formulated from the Spaces model, bounded by the research scope and selected user domain. The design toolbox incorporating personas, scenarios and activity snaps (i.e. snapshots of user activity data) would then direct design components and detail, and help evaluate them.

As the Spaces model places strong emphasis on the visualisation and interaction aspect of Pervasive Personal Information Spaces, the design methodology employed in the research was an iterative process. The complexity of the concept also meant that all phases of finalising the Spaces model, formulating the requirements, developing the design, evaluating the designs, prototyping as well as evaluating the prototypes would be carried out iteratively, with progress in any phase helping to further inform and refine the other phases.

The interface and interaction design of InfoMesh was started early once the Spaces model was developed, with brainstorming sessions to come up with various design ideas and options. Soon with the initial requirements and design tools in hand, a variety of paper prototype designs were drawn up from a selection

of these early design ideas. The preliminary paper designs explored a wide range of alternative interface designs for views, emphasising a variety of interaction and design elements to support navigation, organise and present view content, and manipulate views. The most suitable designs and design elements were then transformed into computer-based mock-ups. (The early paper designs were developed for desktops/laptops, PDAs and also mobile phones, and explored a variety of new interaction and navigation ideas, especially for PDAs. One such idea was the ‘navigation eye’, which provided an auto pan and zoom functionality through a retractable navigation icon visible at the top right corner of a view.)

Using several activity snaps, these intermediary InfoMesh designs were evaluated for appropriateness and refined over several stages. The real-world activity data incorporated into the designs shed light on how the designs and InfoMesh content would be used and interpreted as well as how functional they were. They assisted with designing content as well as ameliorating space and navigation issues, clustered content, information visibility and detail, ambiguous presentation elements and so on. Basic heuristic evaluation of the designs (using material by Nielson, 1994a and b, and Tognazzini, 2003) and interface walk-throughs then further prepared the designs for implementation.

Consequently, the updated designs were slowly incorporated into the InfoMesh prototypes. During the prototyping process, these designs were further adjusted for feasibility and appropriateness, and updated to reflect prototype evaluation through the use of heuristics, activity snaps and user studies. Prototype evaluation will be discussed in the System and Evaluation chapters.

MAPPING THE DESIGN SPACE

The entirety of abstract design ideas (stemming from the Spaces model and resulting requirements), worked out design elements, and interface and interaction designs comprise the design space for Pervasive Personal Information Spaces in this research.

In designing the interface and interaction for InfoMesh, numerous ideas and designs have been drawn up and thought over for developing context-based flexible views, more than would be feasible for implementation. The goal hereby was twofold: 1) to explore the design space and explore what is possible, even if certain ideas would not be feasible yet with the current technology and within the

given time frame, and 2) to bring forth selected designs and design elements appropriate for implementation. As such, although various designs and design elements will be carried over into the prototyping process, some elements may be left as explorations of the design space for informing future research.

We now look at the InfoMesh interface designs at an abstract level, followed by more specific desktop and PDA designs for InfoMesh visualisations and tools.

4.2.2 DESKTOP AND PDA INTERFACE DESIGNS

Central to representing the information space in InfoMesh are *views*. Views provide a variety of perspectives on the underlying information space according to user activities and contexts, visualisation styles, and queries and filters among other things. A key characteristic of these views is that they are flexible (according to the requirements for FlexViews). The user can manipulate them through a variety of tools. They can further be saved for exact retrieval, shared or printed out, and have settings and preferences. Views are closely associated with user activities and goals.

The view designs for InfoMesh, created for desktops and PDAs, explore the design space that forms the foundation for InfoMesh implementation. Some views would only be present on certain devices (especially notebooks and desktops), while the InfoMesh Presenter (the interface component of InfoMesh) and some of the views it provides would be altered and simplified to suit other devices (especially handheld devices). The information space behind the views is however kept integrated and complete.

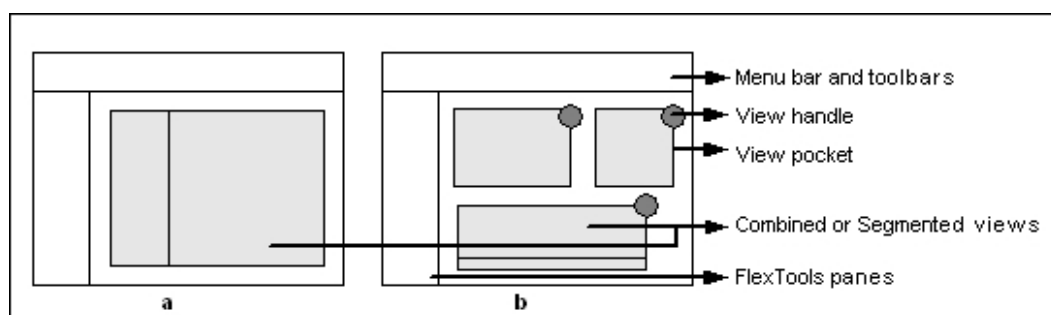


Figure 4-1: Windows in InfoMesh: a) Single view window and b) Multi-view window

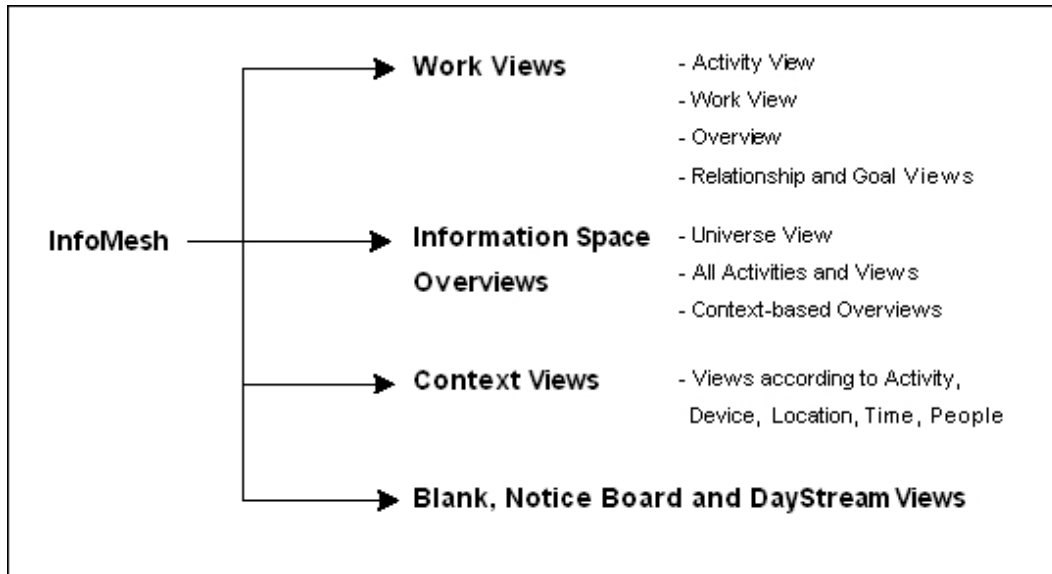


Figure 4-2: Overview of InfoMesh views

InfoMesh Presenter can potentially support single view windows and multi-view windows. Single view windows, as the name suggests, display a single view of the information space. Multi-view windows can display several separate or related views of the information space (a.k.a. *view pockets*), each with a handle for selection and manipulation. Figure 4-1 shows the general layout and contents that these two windows can take on in InfoMesh running on desktops and laptops. InfoMesh Presenter will mainly explore single view windows in the designs and prototype implementations for both desktops/laptops and PDAs.

InfoMesh Presenter would provide several kinds of views. Views in both the single view and multi-view windows can take the form of any of these view types. There are several everyday work views and pre-set views, information overviews, and context-based views that can be combined easily. ‘Combined views’ have multiple segments that each match a particular visualisation type (e.g. folder views can be combined with a spatial workspace, or a map view with a temporal view of the same information). See Figure 4-2 for an overview of the main kinds of views.

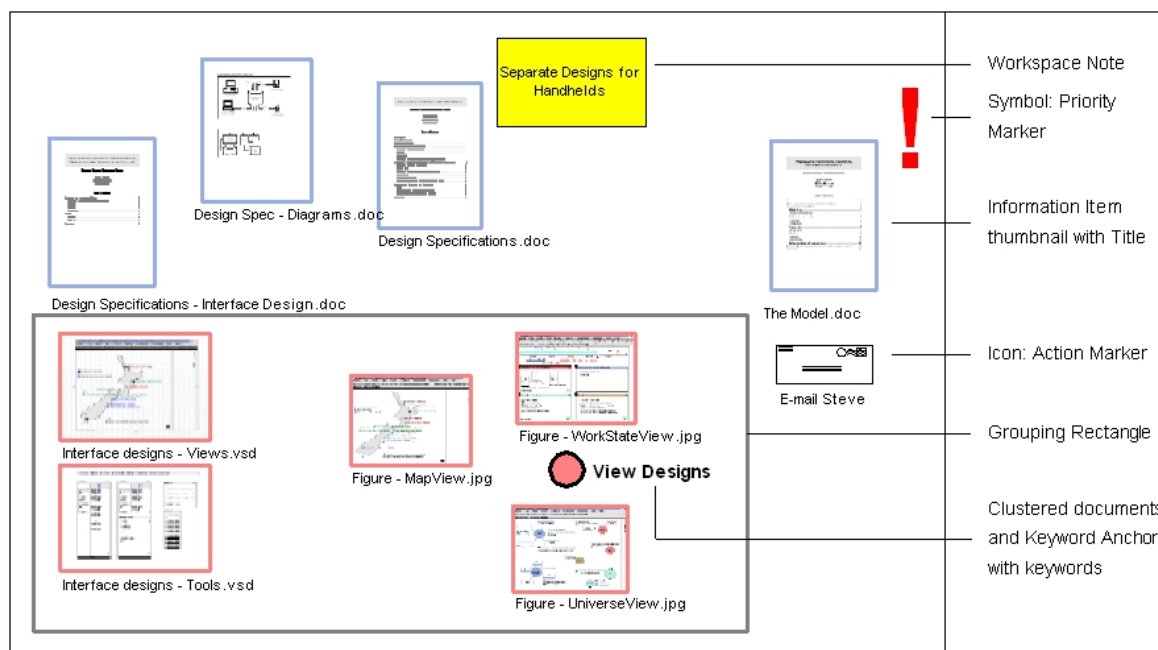


Figure 4-3: View contents: Information items, notes and markers.

Views can contain a variety of items, details and markers to create rich, associative content. These include references to information items through icons or thumbnails, with titles and file details as specified by the user; workspace notes and keyword anchors associated with items; workspace or action markers (symbols and icons that act as landmarks, priority markers, or real-world references to objects and tasks); and shapes like rectangles and circles for grouping and emphasising items. Information items can refer to documents, images, e-mail, sound clips, URL's, bookmarks and so on. See Figure 4-3 for an example of view items.

The various objects on the workspace can be arranged and grouped together, colour-coded and annotated. Visual cues can also be provided for the information item references, such as making them larger, with thicker borders or prominent colours according to frequency of use, file size, file importance and so on.

Navigation in InfoMesh can occur in several ways. Firstly, navigation can mirror web browsers, where view traversal and action history can be tracked, so that users can go back and forward through the views they've visited. Secondly, users can select a particular activity or view to display, as well as switch between specific types of views (such as activity or context view) for the same activity or information. Finally, users can move within a view by using overview windows,

navigation buttons to go to the beginning, end, top or bottom of the views, as well as by panning and zooming across the view workspace.

The computer-based desktop/laptop and PDA mock-ups follow next with descriptions for InfoMesh work and pre-set views, overviews, context views and FlexTools. The designs are presented with activity snap data that was used to understand, inform and improve the designs. The activity snaps pertain to Lisa's activities, including research and study related activities, some of which have been built using activities carried out as part of this research work (e.g. preparing design specifications, communicating with supervisors and other students). The main designs are annotated with brief activity scenarios or task scenarios that link the activity snap data back to Lisa's work.

WORK AND PRE-SET VIEWS

InfoMesh provides several everyday work views to support working on single and multiple activities (*activity* and *work views*); surveying the information space and reviewing work progress (*overview*); managing goals and tasks (*goal view*); and viewing and changing relationships between user goals, activities, views and contacts (*relationship view*). The user can set any of these views as the default opening view. In addition to these, InfoMesh provides a special '*blank view*' that the user can set to view any segment of the information space by altering settings for information details, visualisation styles and contexts using FlexTools. InfoMesh also provides a '*notice board*' view mimicking real-world notice boards. Users can place notes, action markers and messages on the notice board workspace to act as reminders.

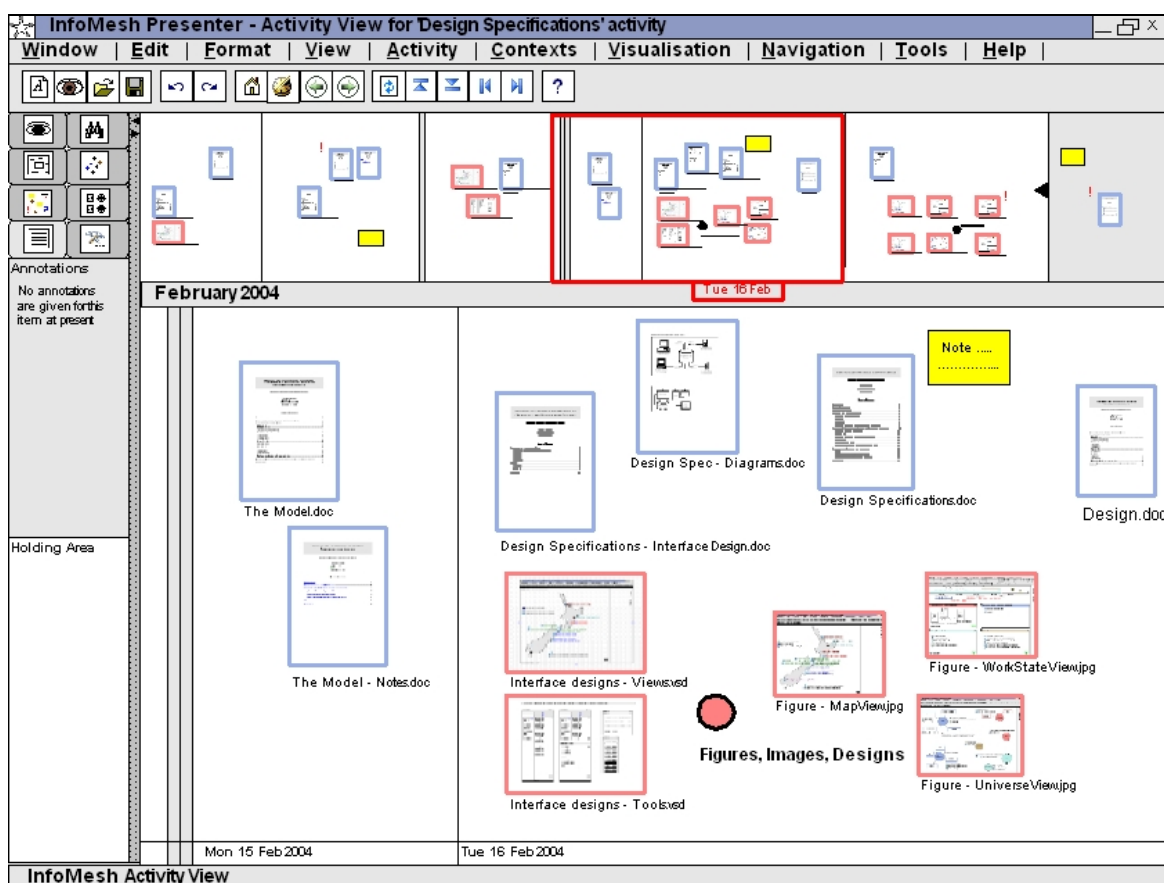


Figure 4-4: Activity View for 'Design Specifications'

Activity scenario for 'Design Specifications' activity

Lisa is currently tracking her research work using InfoMesh, which includes work on specifying design information for a prototype system. She largely works with the activity view in InfoMesh, which displays her information items and annotations chronologically, allowing her to resume her work easily when she next returns to the activity. The activity view also allows her to keep track of how far she is into the design work, especially as she also adds distinct markers to the workspace to denote milestones reached.

Lisa started her design specifications by developing a framework for her design work, before brainstorming designs on paper and reproducing and refining them on her desktop. On InfoMesh, she annotates the designs and the workspace with reminders, comments or ideas she has as she carries out the activity. When Lisa's away from her desktop or laptop, she likes having access to her activity trail and designs from her PDA. They prove useful as a reference when she's travelling and jotting down notes on paper.

Activity View: This is the single activity view as presented in TimeSpace, with a variety of modifications (see Figure 4-4 for the desktop design). The view presents an integrated temporal and spatial view of a single activity, supporting

task focus, reminding and information arrangement. Among other support, the FlexTools panel further provides a holding area for important documents within the activity, annotations and keyword categorisation of clusters for the view. The view allows users to pan and zoom into the temporal and spatial views of the activity and enter information and notes for a future date to act as reminders. Lines separate days on the workspace and these lines also give information on work continuity. The design example shows that Lisa carried out some work for the 'Designs Specifications' activity on two consecutive days (Monday and Tuesday), but had done nothing during the weekend before. The design also shows that she's currently working on her design mock-ups while referring back to the specification documents, and has some notes and reminders set for the near future.

The toolbar for the view provides the standard InfoMesh window toolbar with buttons for opening, creating and editing activities and views, and navigating between visited views and within views. A further activity view toolbar can provide options for selecting specific activities and switching between views for the same activity.

A PDA version of the view design is presented in Figure 4-5 for an activity that tracks an artist's work of interest to Lisa. Thumbnails are only presented for items flagged as important or documents that Lisa requested to have on the PDA, with a little icon indicating that those items are directly available on the device. Other information items can be downloaded when needed. In this design, using activity snap information emphasised the need for a distinction between important items and those that are not immediately necessary for the activity to avoid a clustered workspace. This information is still perceptible and easy to bring to the fore when needed.

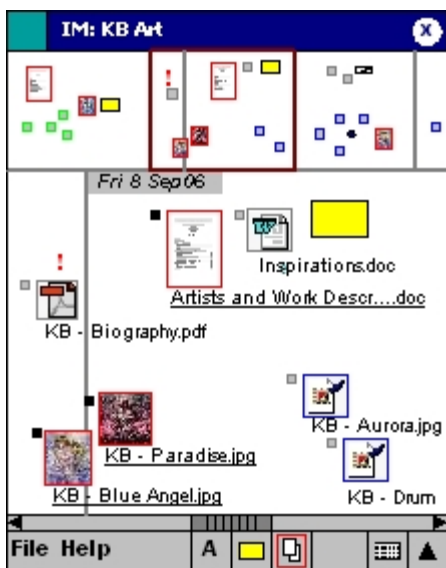


Figure 4-5: PDA Activity View for 'KB Art'

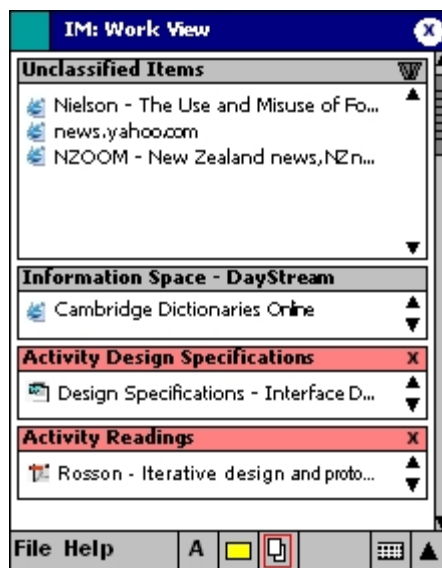


Figure 4-6: PDA Work View

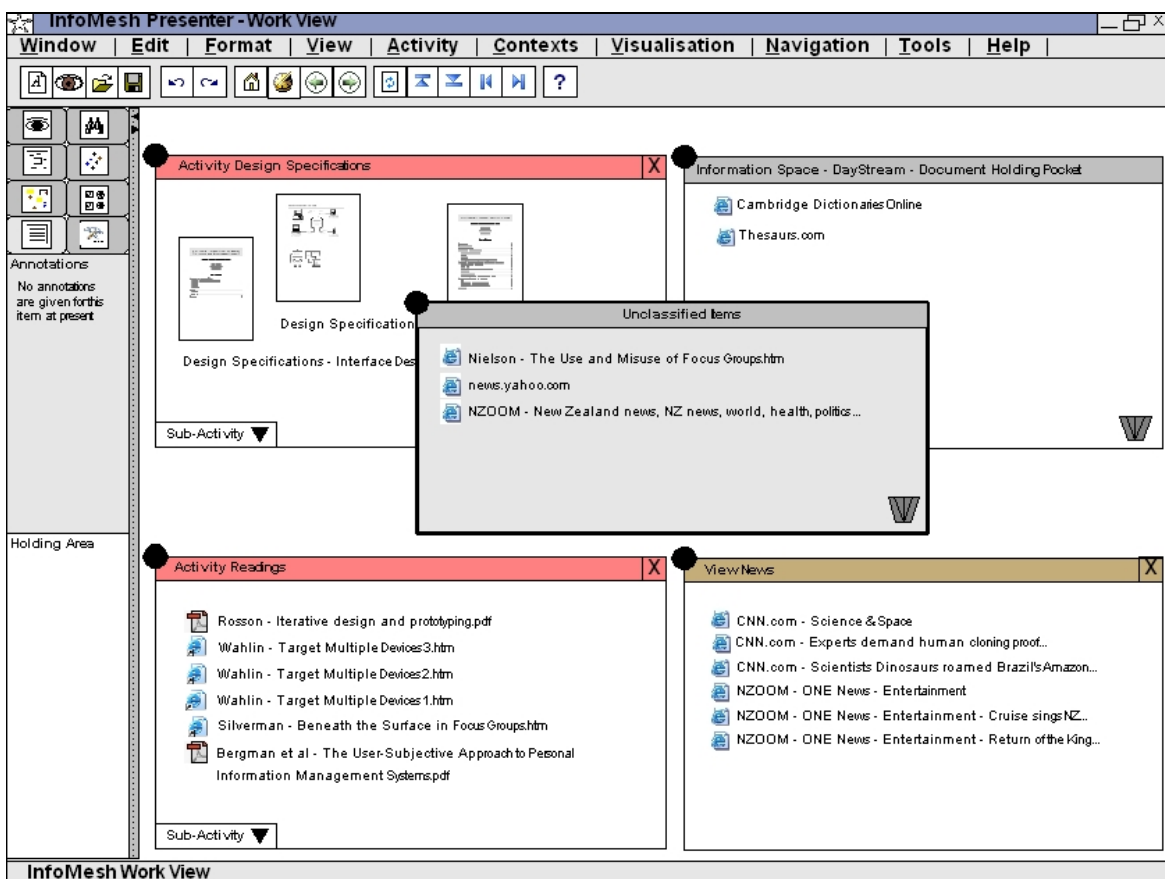


Figure 4-7: Work View

Task scenario for working on multiple activities

Lisa's downloading some articles that relate to her design specification work, while she's online checking mail and reading some news. As her work spans several activities, she's using the work view in InfoMesh, with the relevant activities or views

open.

As Lisa downloads articles, they initially appear in the unclassified items if they are unfamiliar and difficult to automatically assign to an activity. She just drags them across to both the 'Readings' and 'Design Specifications' pockets to review later. At the end of the online session, she just deletes any items she's not interested in keeping from the unclassified items pocket.

When she returns to the design specifications work, the articles she's downloaded are immediately visible as the most recent additions to the workspace, so that she can peruse them, group them with the documents they inform and add any important notes after readings them. Her 'Readings' activity also lists the articles, so that she can keep track of her entire bibliography in one place and add new articles to her citation software when she next visits the activity.

Work View: When working on multiple activities at the same time, users can work with the work view (see Figure 4-6 for the PDA design and Figure 4-7 for the desktop design). This multiple-activity view makes use of *pockets*. Pockets can be activities or views that the user can drop information items into (e.g. documents, messages, and contacts). The user can choose to have pockets visible for several activities or views for activities they are working on. The view has a special '*unclassified items*' pocket for information items that are newly created or ambiguous as to where they belong. Users can at any time drag and drop these items into their activity and view pockets, or delete them if unnecessary. Next to the standard InfoMesh window toolbar, a further work view toolbar can allow users to quickly select or de-select specific activities and views for presentation within the workspace. In the design, Lisa has for example selected the activities 'Design Specifications' and 'Readings', and a view on the 'News' activity.

If an item does not belong in any particular activity or view, the user can keep it in the information space *DayStream* pocket. This document-holding pocket holds all the items that the user wants to keep, but does not want to associate with a particular activity or view. For example, Lisa keeps links to an online dictionary and thesaurus there, as she uses those regularly while writing up reports. The DayStream view can show, according to the user's choice, only these items or display all the information items the user created, accessed or modified during their day-to-day interaction with their information space. Visualisation settings can be changed individually for each of the pockets through the FlexTools panels.

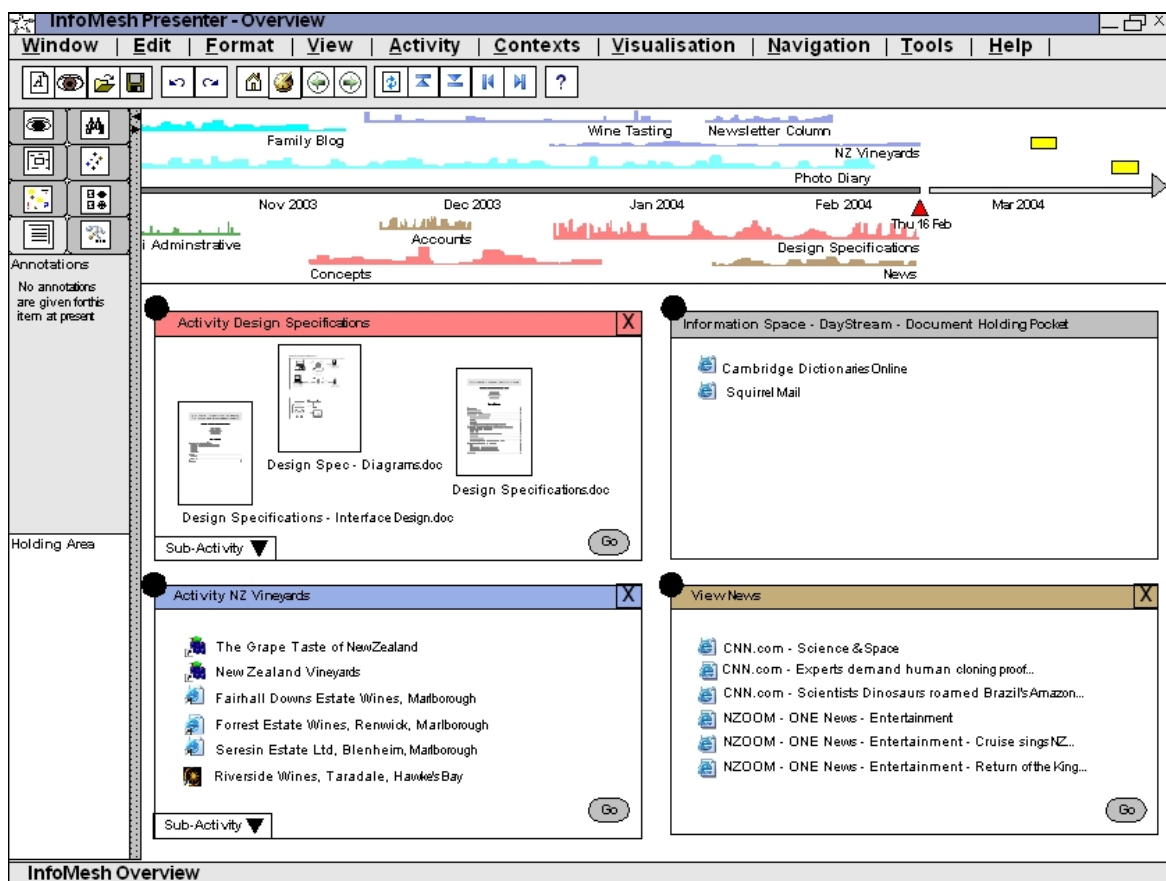


Figure 4-8: Overview

Task scenario for reviewing recent activities

After opening up InfoMesh, Lisa often first looks at the overview to see what she's been working on recently and to review the state of her work. Looking at the timeline, she sees that she has not updated her family blog in a while, even though she took plenty of pictures on her last trip away. She also feels that it is time to start working on some prototyping for her research work. As she already has a busy schedule this week, she adds a couple of reminders in the near future for starting her prototyping and updating her family blog with the new pictures. Lisa then clicks on the 'Design Specifications' activity pocket, which takes her to the corresponding activity view. The view reminds her of her most recent work on the activity, and she resumes her work from there.

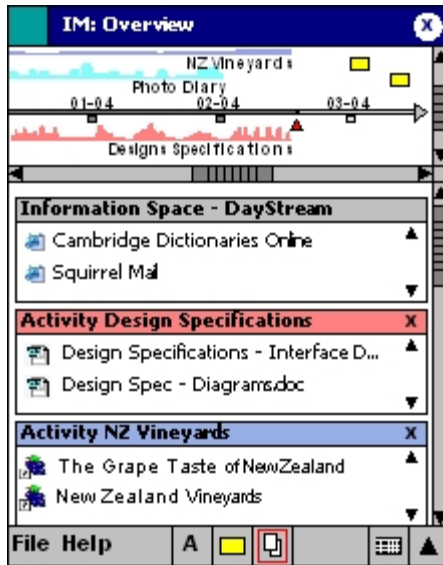


Figure 4-9: PDA Overview

Overview: The overview (see Figure 4-8 and Figure 4-9) allows users to survey the activity work that makes up their information space and also acts as a reminder of recent work. The view displays pockets for the most recently accessed activities or views with their corresponding information items, as well as an overview timeline of all activities. The overview timeline gives an indication of which activities are being carried out and the activity progress. For example, Lisa has most recently been reading up news, working on her design specifications and visiting vineyards web sites. Her most intense work has been on her ‘Design Specifications’ activity. She has further colour-coded related activities using the same colour, such as her research activities ‘Concepts’ and ‘Design Specifications’ for example.

The overview is similar to the Overview Window in TimeSpace, and is the default view on entering InfoMesh. (Users can set other views to be the default view at any time.) Users can specify the number of recent activity and view pockets they want to see as well as the number of items. FlexTools can be used to individually vary the presentation of the view pockets. Similar to the work view toolbar, the overview toolbar presents options to select activities and views to be included in the workspace as well as an option for selecting the time frame and granularity for the overview timeline.

Goal View: User activities are closely linked to goals, tasks, and schedules. InfoMesh's goal view allows the user to list their main goals with task, progress and date information. For each goal, this view provides a listing of related activities, views and important documents for quick access. Similar to the work state view, this view also displays an overview timeline of all activities for a 'big picture' overview with markers to indicate goal/task deadlines.

Relationship View: Users can, if they choose to, create links between any of their activities, views, devices, goals, views and contacts and so on through this view. Certain relationships can be created automatically from usage information, such as an association between an activity and a device, or an activity and a view.

Relationships that are created automatically, explicitly in this view or through options in any of the other views will subsequently allow information to be presented according to the way the user relates to that information. Relationships can be changed or broken at any time. Many of the FlexTools options (such as filtering or viewing information according to certain contexts and details) can also be applied to the relationship view.

OVERVIEWS

As InfoMesh keeps track of the user's entire information space across devices and applications, overviews form an important viewing tool within the system. InfoMesh supports several kinds of overviews, namely views showing the abstracted content of the entire information space, overviews of segments of the information space and of activities and views created by the user, as well as context-based overviews. All these views are again kept flexible through the use of FlexTools.

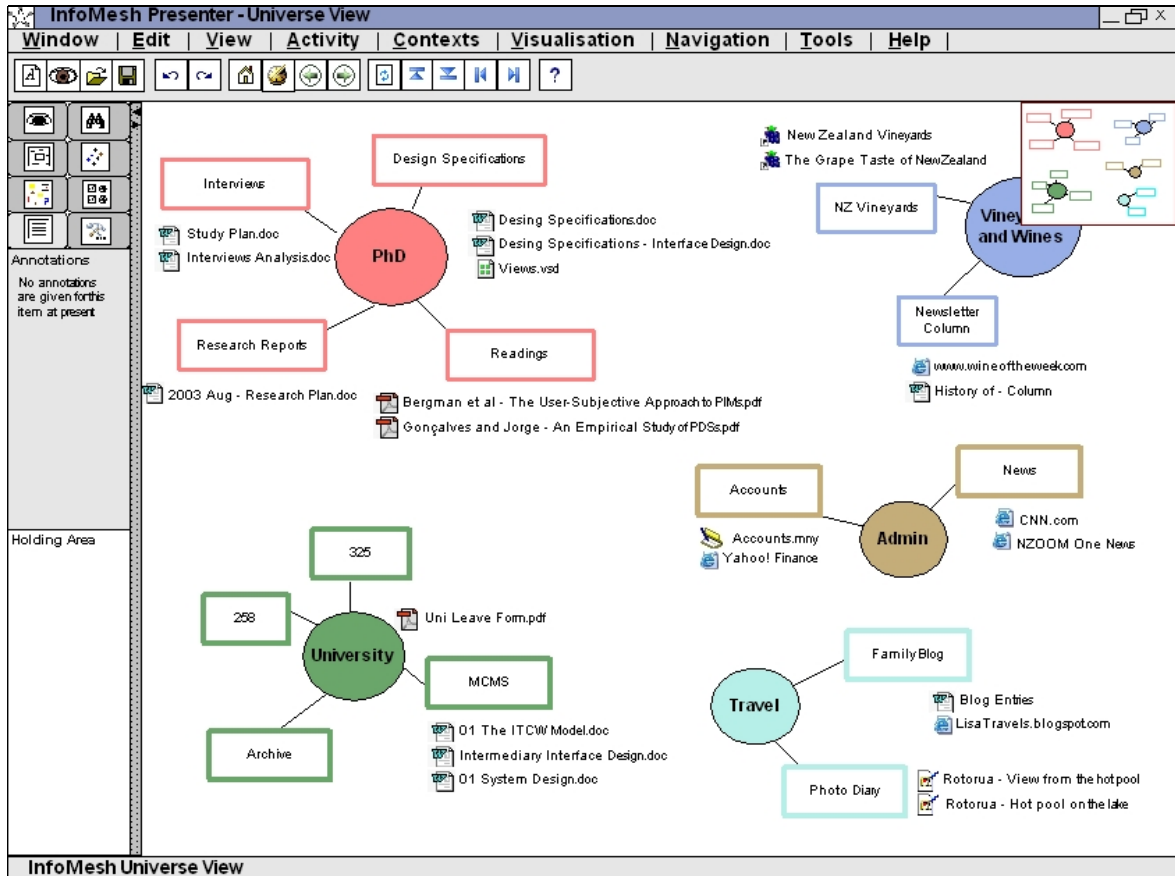


Figure 4-10: Universe View

Universe View: Within InfoMesh, this view presents an abstracted overview of the information space (see Figure 4-10 and Figure 4-11). In the default setting, the view presents areas of interest with related (frequently accessed, recently accessed or high priority) activities with information items previously flagged as important. The view presents areas of interest or high-level activities as ‘planets’, with planet size matching duration, number of activities, number of documents or priority level as specified by the user.

Hovering over or selecting a planet expands the area and shows all related activities for that planet and other frequently accessed documents for these. Items can be bright or faded and of different sizes to indicate importance or recency of activity interaction, e.g. Lisa’s PhD area of interest can be bright and large, whereas the MCMS or Archive items could be faded as they are older and not frequently accessed. The universe view and contained planets can also be based on the user’s folder hierarchy and frequency of accessing certain folders and files.

Using FlexTools, Lisa can choose to view additional information in the view such as views she's created and her activity goals. She can also choose to aggregate details on an activity, or filter out certain information such as bookmarks or images and so on.

The designs for this view incorporate selected data from several activity snaps to depict a snapshot of Lisa's information space, highlighting different aspects of her information space than the overview (specifically the overview timeline) discussed before. Seeing this data in the view gave deeper insight into the functionality and interaction that Lisa may wish to have in the visualisation, such as panning and zooming through the view, hovering over areas of interest and activities to see more detail appear, and filtering the space to view the information space as it was for a particular time-frame or according to some keywords.

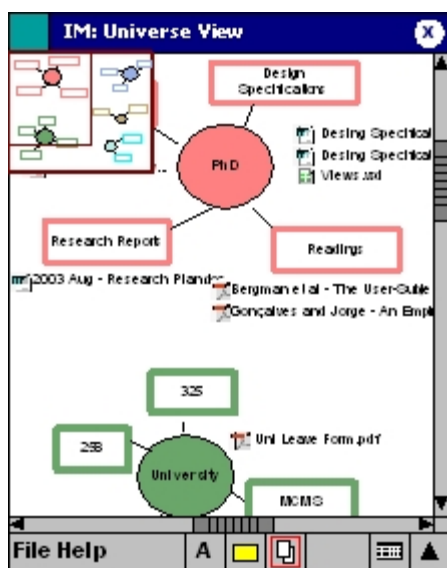


Figure 4-11: PDA Universe View

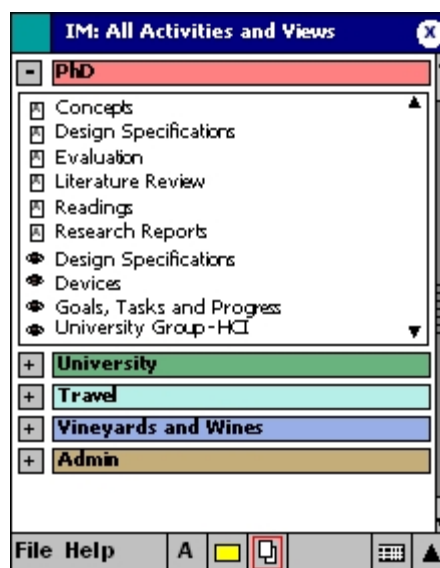


Figure 4-12: PDA All Activities and Views

All Activities and Views: This category-map style view (see Figure 4-12 and Figure 4-13) presents activities (denoted by an 'A') and user-specified views (denoted by a small 'eye' icon) according to areas of interest. Activities or views may be present in more than one area of interest. The user can select to view all or a particular set of areas of interest in the view. Recently accessed views can also be visually presented with a thumbnail view for easy recognition on the desktop version of the view.

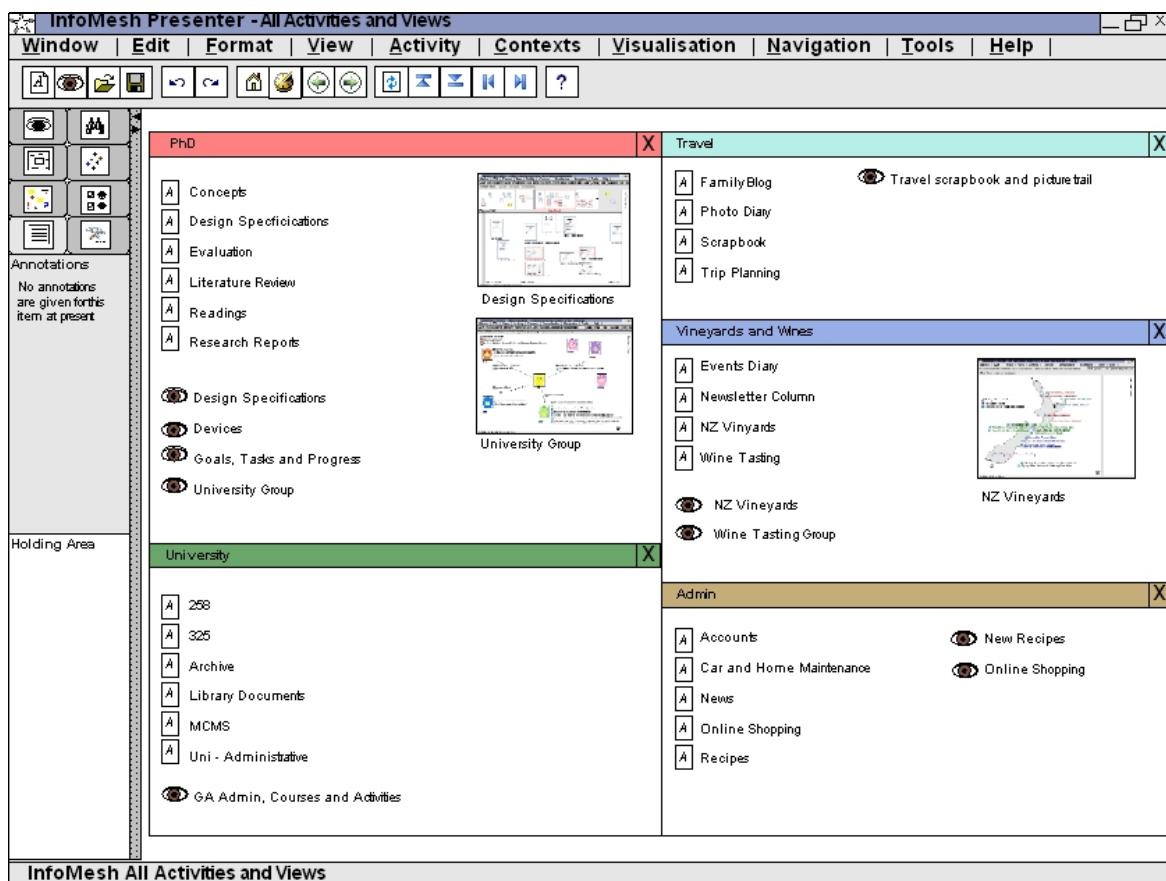


Figure 4-13: All Activities and Views

Context-based overviews: The InfoMesh design space offers several standard context-based overviews. Other context-based overviews can be derived from, for example, the universe view by using FlexTools (e.g. universe view filtered for a particular device or location, or material used by a particular user group).

The standard views include a chronological view of the changes to the information space by device, an activity comparison overview, and a folder view of activities and views. The first view displays a timeline of activities for each device used by the individual, supporting device-based comparisons of activities and activity levels. The view would include information item references, views and activities created and accessed, action markers and so on. The second view is similar to the activity comparison view in the early TimeSpace designs (see Krishnan, 2003) and presents a timeline of activities (such as the one in Figure 4-8), with chronological activity workspaces (such as the one in Figure 4-4) for activities current at any given time. This view would support making comparisons between activities. The last view provides a standard folder view of activities,

sub-activities, views and corresponding information items. However here, an information item may be present in more than one activity, sub-activity or view, and user-specified view annotations enrich the listing of information items (e.g. colour, notes, symbols and action markers, and priority information).

CONTEXT VIEWS

Lastly, InfoMesh provides users with access to views based on contexts (most specifically activity, location, device, time-period and social group). These context-based views can be created by choosing a view (e.g. an activity view, filter or query results view, blank or existing view) and altering the view according to one or more context categories using FlexTools.

Context views for a single activity can be selected easily by switching to the required context. For example, when Lisa has her ‘Wine Tasting’ activity open as an activity view, she can simply switch to the social view or location based view for the same activity.

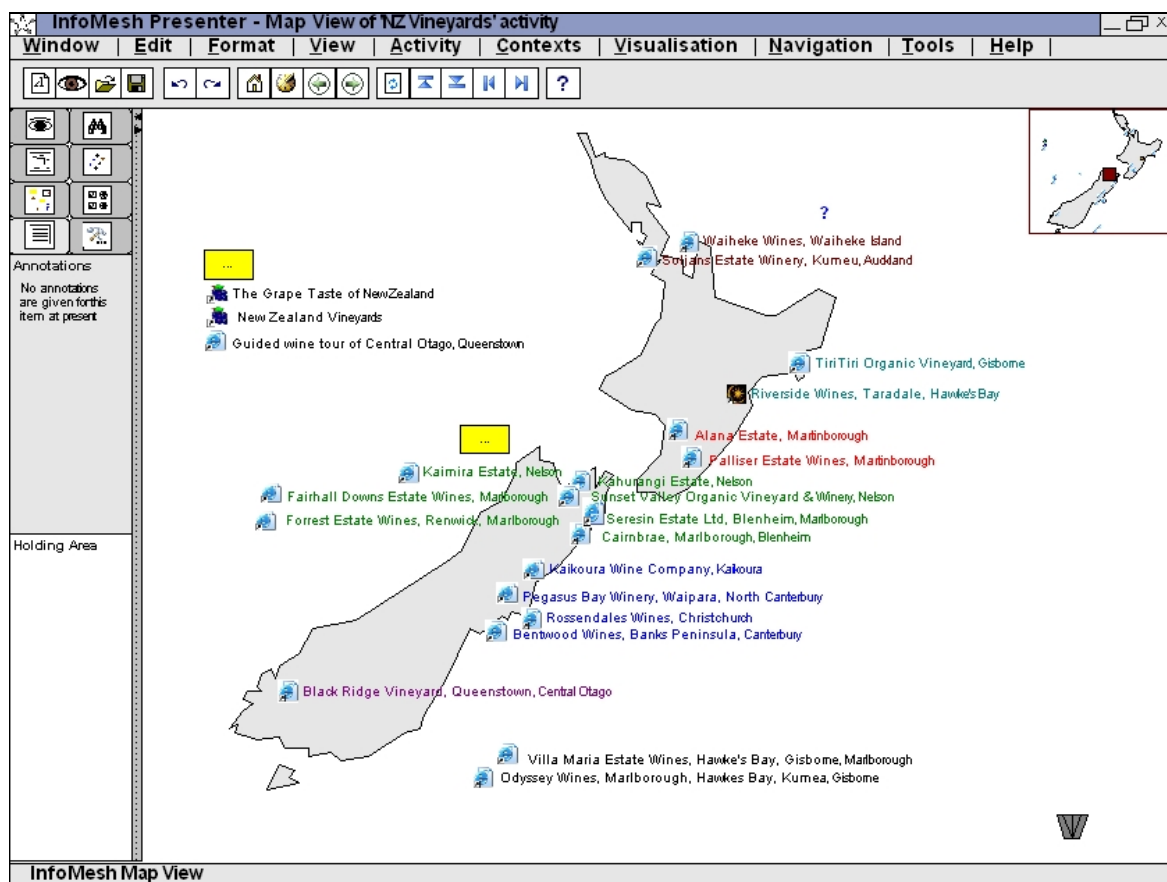


Figure 4-14: Context View – Map View of activity ‘NZ Vineyards’

Users can apply different visualisation styles to the view, and details may be filtered out using the ‘views and display details’ or ‘query and filters’ options in FlexTools. Combination views are also possible where two different visualisation styles are applied to the same information and presented in adjoining segments of the view. Here are some examples:

- *Activity*: Activity-based views may relate to a single activity or multiple activities filtered for a specific set of items using FlexTools (e.g. an activity overview by presenting all information items in clusters in a single large workspace, with an activity-based folder listing).
- *Location*: Location-based views may relate to a building (e.g. research papers related to labs in a view using a map of the labs), the country (e.g. bookmarks of vineyards and wineries shown on a map of NZ, see Figure 4-14 and Figure 4-15), the world (e.g. upcoming conference details and submitted papers on a world map) and so on. These views can also be based on category maps (e.g. people and contact details organised on a spatial map with different areas representing different departments) or object maps (e.g. to-do list organised on a spatial map around objects like the phone, car, home, computer, workplace, city shops and so on). The user can create maps, such as a building, lab or house map, or different category maps, and use these in InfoMesh. As InfoMesh supports panning and zooming, maps can be of different sizes to suit the user’s work.
- *Device*: These views can filter out information belonging to a set of selected devices (e.g. a network view of devices and corresponding activities, a hierarchy of recently viewed images by device).
- *Time period*: Views according to time period can filter out all information accessed at a set time across contexts (e.g. all bookmarks visited within the last week in a calendar week-view).

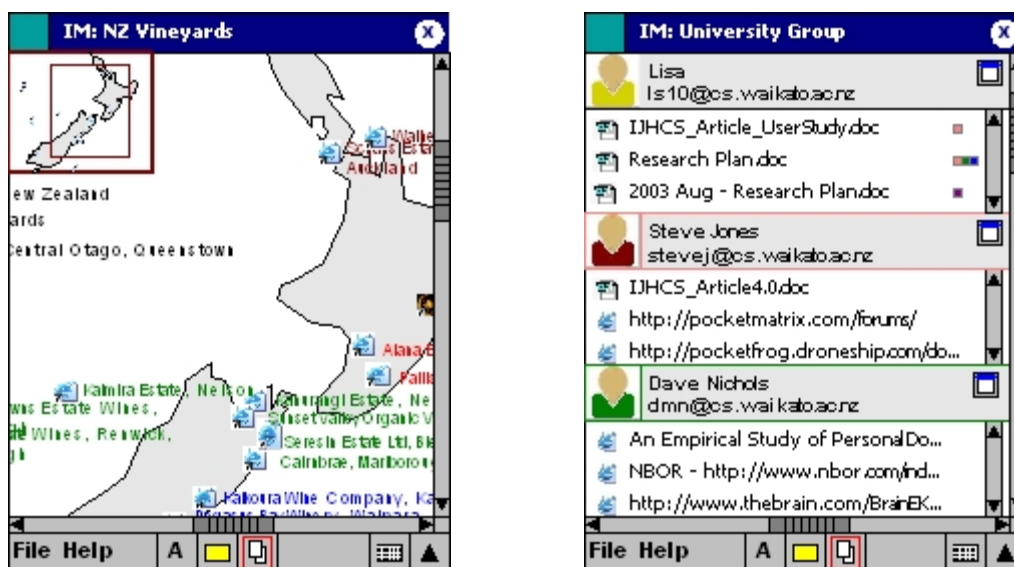


Figure 4-15: PDA Map View for 'NZ Vineyards' Figure 4-16: PDA Social View 'University'

- Social network: Social views help present information items in relation to different people. They can be colleagues, friends, publishers, basically any and all individuals a user shares documents with and so on (e.g. network style view relating URL's and documents shared with members from the University group, see Figure 4-16 and Figure 4-17). Lisa's activity snap data and test tasks for the view showed that the graphical network-based view seen in Figure 4-17 would be quicker and easier to interpret at a glance than an alternative design that used a list-based visualisation similar to the PDA view in Figure 4-16. Hence this view design was one of the designs carried over into the prototyping phase. The graphical view design offers one way of displaying authored and shared items using the network style relationships, though different variations can be considered.

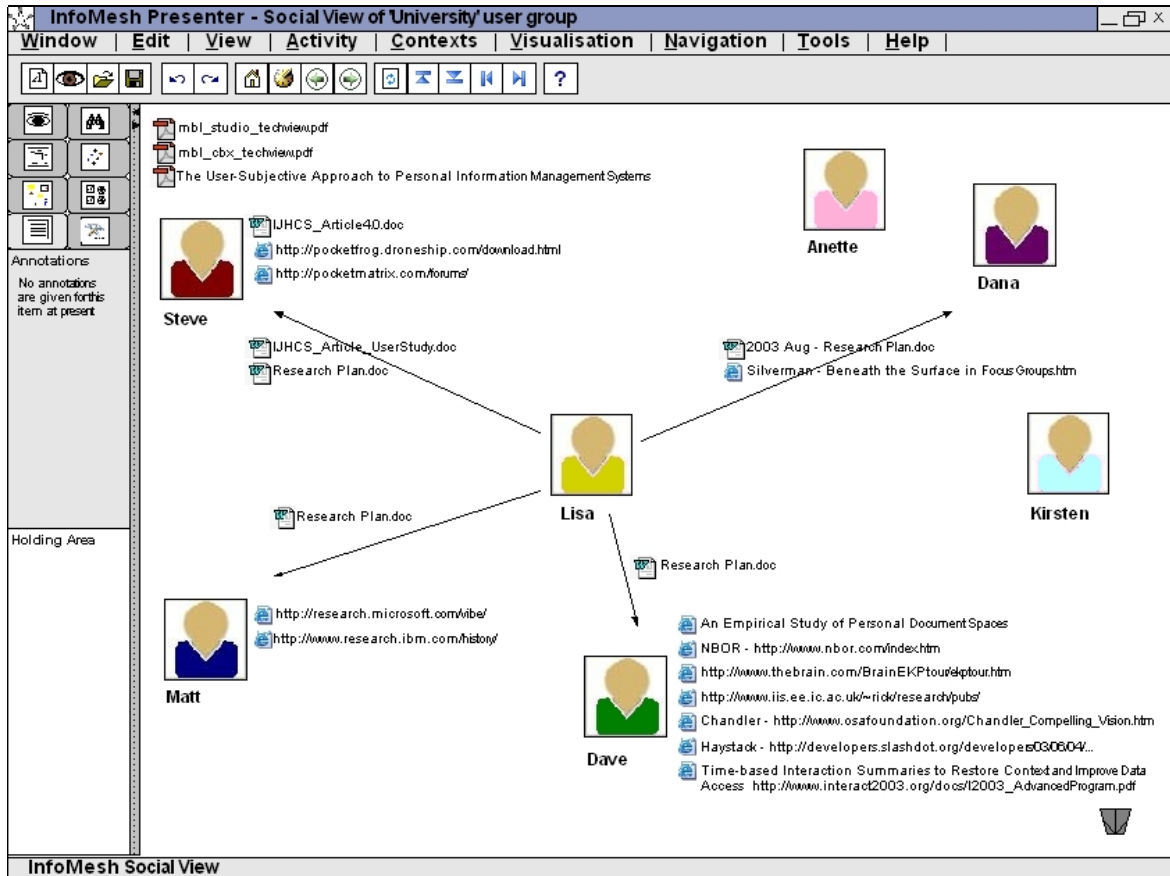


Figure 4-17: Context View – Social View for the ‘University’ user group

Task scenario for viewing information communicated by the ‘University’ group

Lisa communicates with her supervisors and fellow students by email, receiving and sharing information relating to her research work. She has created a user group ‘University’ to keep track of everyone she communicates with in relation to her study. Lisa now has some time available and wants to retrieve some of the articles her supervisors have suggested she read. Lisa chooses to view the documents and URLs that they have sent her by switching to a social network view in InfoMesh for the group ‘University’. The view brings together all communications between Lisa and the group members, across her different research activities. She looks through the shared documents and locates a few papers of interest. She prints them out to read and annotates them on the view as printed out for perusal.

As seen in the designs and descriptions, different visualisation and presentation techniques can be applied to InfoMesh views. The views are kept flexible by allowing the user to change them on the fly according to these techniques, which include variations of:

- Information item details, appearance, and arrangements. These include colour, size and shape coding, use of text and thumbnails, clustering, and different levels of information item detail and attributes presentation.
- Information presentation styles, including lists, hierarchies, spatial layouts, temporal layouts, networks and maps (Shneiderman, 1996).
- Interactive presentation styles, such as detail-on-demand, filter and queries, overviews, pan and zoom views, information relationship views, and history-based views (Shneiderman, 1996).

FlexTools is described next, which provides these options.

FLEXTOOLS

An important aspect of InfoMesh is view flexibility. FlexTools provide view flexibility, versatility and control to suit different situations, types of work or information, visualisations, individuals and their preferred way of interaction, and work styles. FlexTools and the options they offer support contextualised, personalised presentation of information and depend on the view that is currently open or selected. The options are presented in tractable panels on the left-hand side of the views for desktops (and in simplified form as part of the menu bar and toolbar in PDAs). The options are organised around the following categories: views and view details, query and filters, contexts, visualisation, workspace markers and tools, information options (including archiving and sharing options), annotations and document holding, and settings and preferences. FlexTools also supports an activity browser. Though the FlexTools panels provide various options, individuals may choose to only use certain types of views, options, view elements or visualisations consistently due to their work styles and preferences.

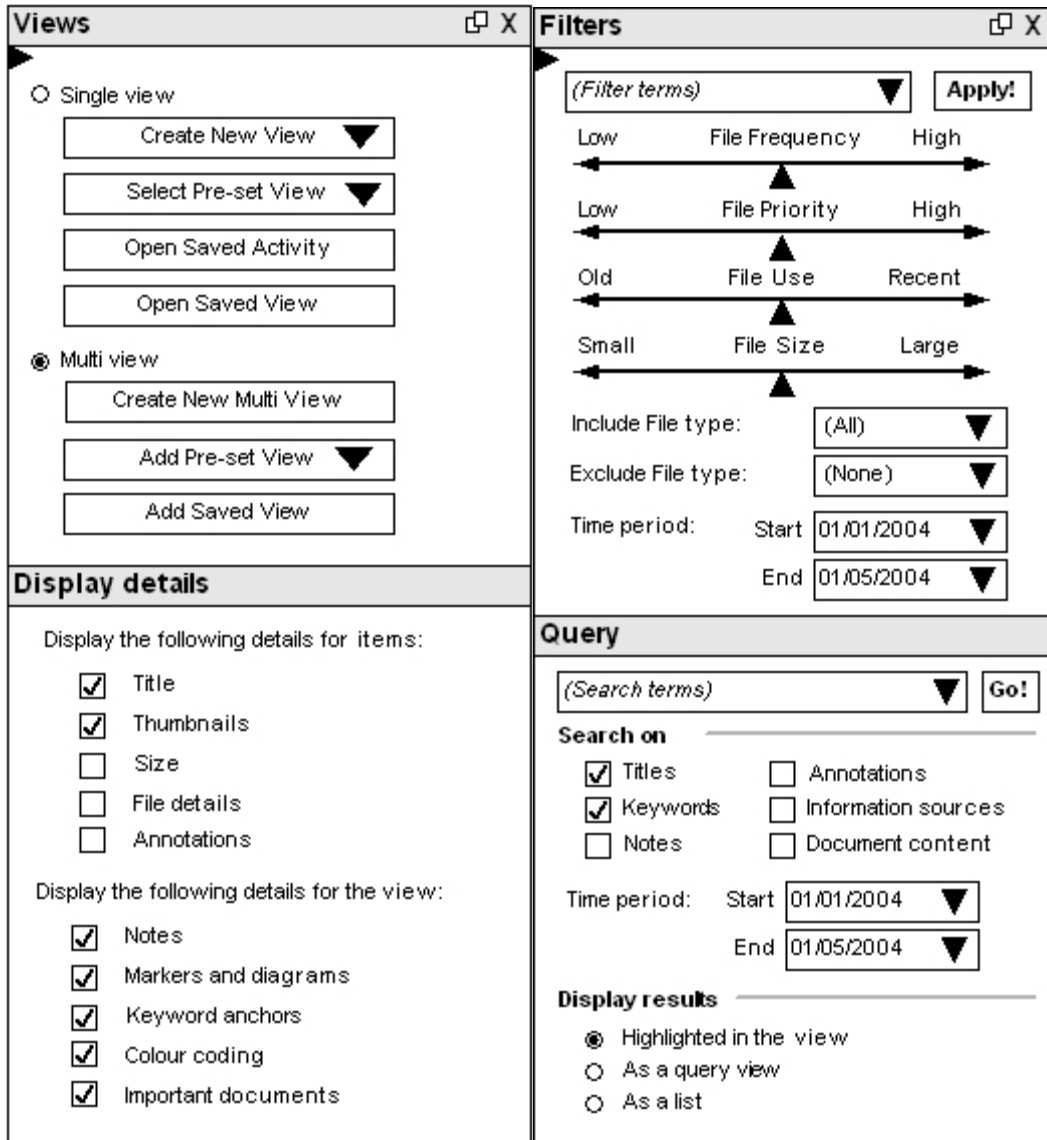


Figure 4-18: FlexTools Panels - Views and Display Details, and Filters and Query

Views and display details: The views and display details panel (Figure 4-18) allows users to choose from either a single or multi-view option. The single-view allows the user to create or open an existing view, open a pre-set combination view (such as the work view, overview, or activity and views overview), or create a context view (such as an activity, map, social, device or temporal view). The multi-view allows the user to add specific existing and pre-set views to the multi-view workspace (e.g. Lisa can view both the activity and map views for her ‘NZ Vineyards’ activity side-by-side). The panel further allows users to select the details presented on the workspace, such as thumbnails, notes and markers. For

most of the views, Lisa for instance may prefer to see only titles and thumbnails for information items without further file details.

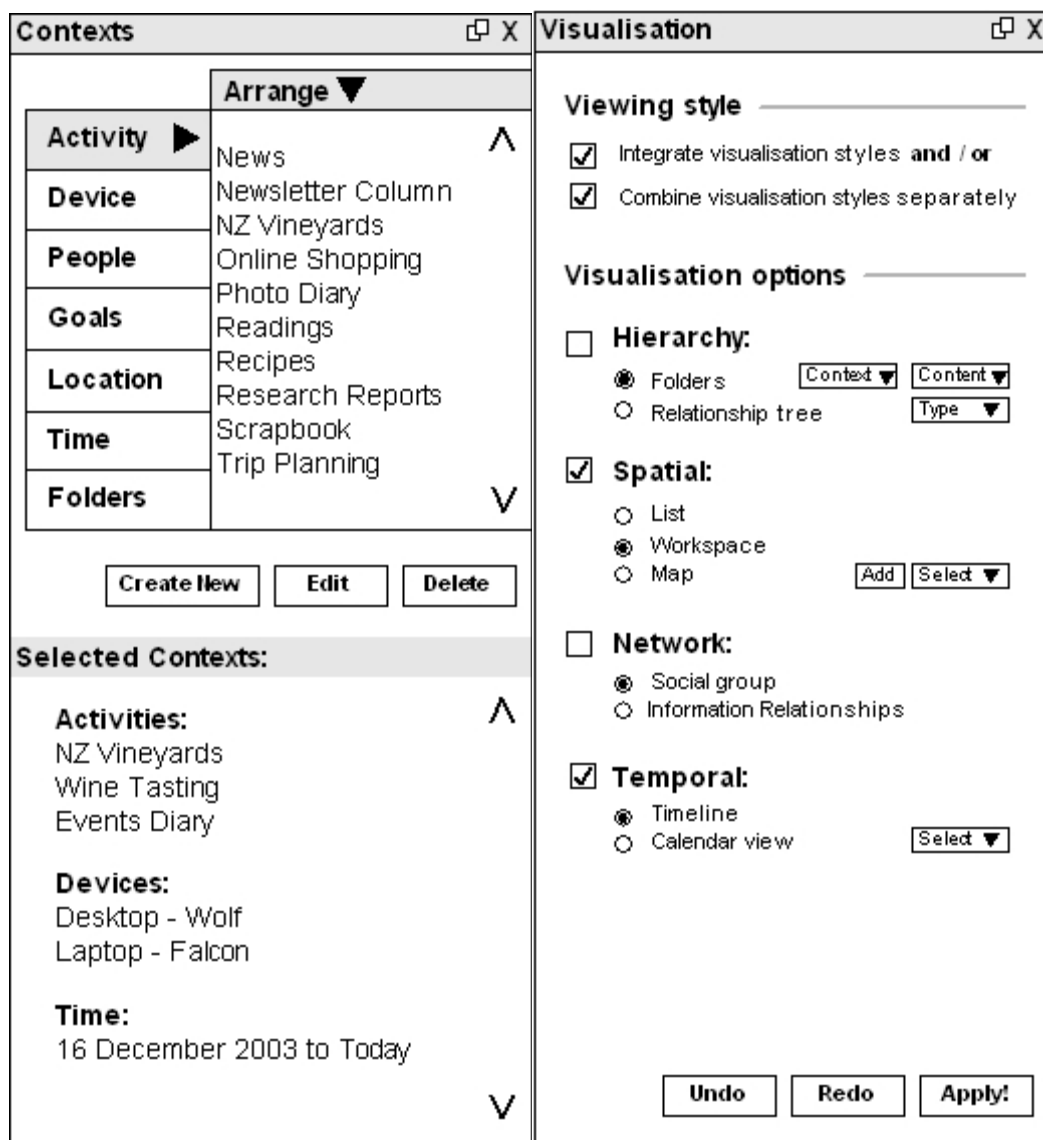


Figure 4-19: FlexTools Panels - Contexts and Visualisation.

Query and filters: The query and filters panel (Figure 4-18) allows users to firstly filter out unnecessary information. The panel provides dynamic query and selection style of manipulation of view items according to frequency of use, priority, file details (e.g. size, recency), file types and relevant time frames. The query options allow for a search to be conducted on the current view. The panel provides options for carrying out the search and displaying the results. The users can choose to view the query results highlighted in the view, as a result set displayed in a separate query view with contextual information, or as a tractable

result list. The query view will show each result in a separate ‘view snapshot’ showing the time the item was accessed surrounded by other items and notes from the same time, activity and view. The query view or query results presented in the view will highlight the results (or fade all other items in a filtered view), so that the results stand out even while the context remains.

Contexts: The contexts’ panel (Figure 4-19) lets users manipulate the activity, device, people, goal, location, time period (e.g. cycles, set intervals) and categories / folders context of the view. A combination of contexts can be selected at once. At all times, the panel lists exactly what the context is of the current view (e.g. Lisa’s selected view includes activities ‘NZ Vineyards’, ‘Wine Tasting’ and ‘Events Diary’, on her desktop and laptop, in the last two months). The panel also allows users to create new instances of the contexts (such as a new activity, device or contact), as well as edit and delete existing contexts. Users can save a view altered through filters and contexts under a different name, so that different views exist for the same underlying information, providing different perspectives and interpretation of the information space.

Visualisation: The visualisation panel (Figure 4-19) lets users apply a single or combination of visualisation styles to the current view. These include hierarchy (e.g. folders according to context and content, relationship tree), spatial (e.g. linear list, workspace, map), network (e.g. social group, relationship network) and temporal styles (e.g. timeline, calendar view such as day, week or month). The panel also allows users to choose between an integrated and a combination view. The visualisation styles can be 1) integrated, where the view combines information from two contexts or visualisation styles (e.g. a workspace displaying items in chronological order), and/or 2) combined, where there are effectively separate segments to the view, each of which presents information according to a different context or visualisation style (e.g. a map displaying items by location with a timeline that shows the same items according to chronologically access). Figure 4-20 shows an example of the latter combined view for Lisa’s ‘NZ Vineyards’ activity. The map view segment mirrors the timeline selection by highlighting the corresponding items. Only certain selections and combinations

are theoretically possible with specific views, so the options presented through this panel would have constraints.

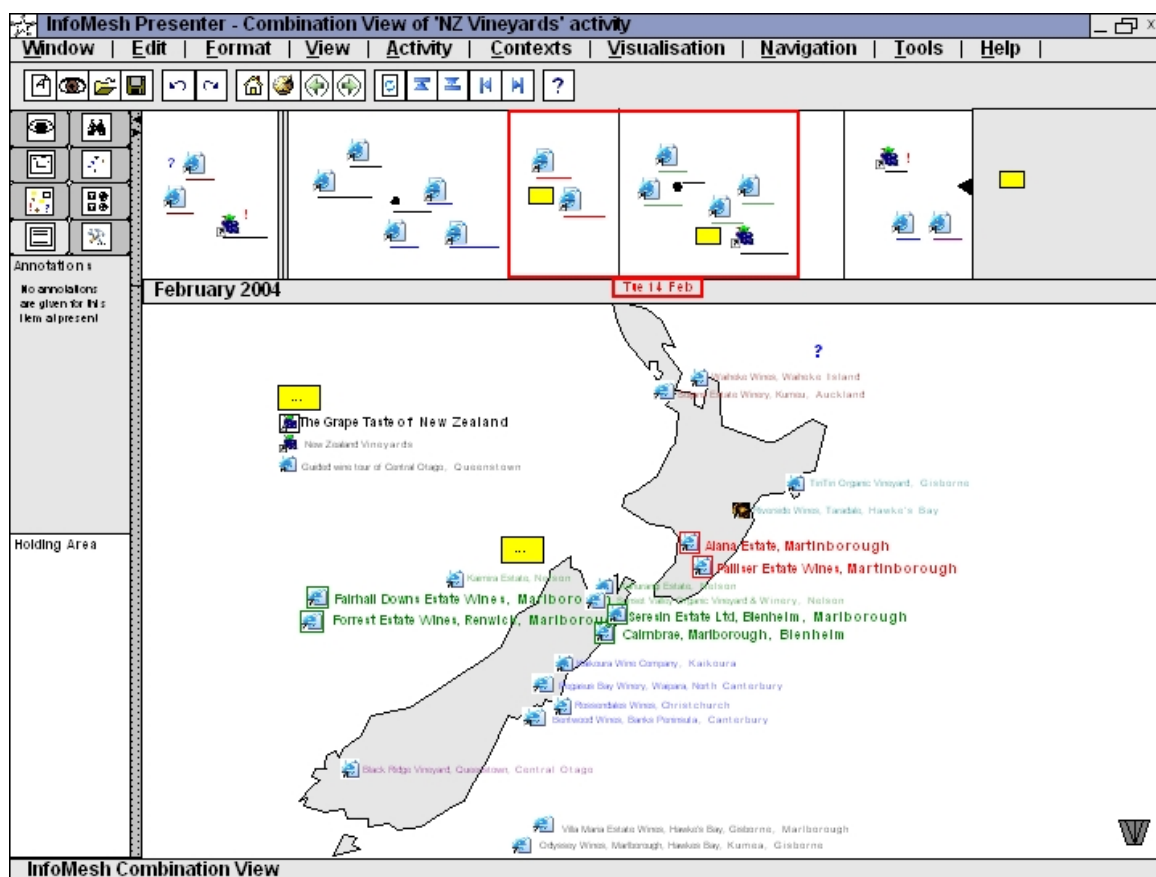


Figure 4-20: A Combination View displaying temporal and map visualisation segments

Workspace markers and tools: The workspace markers and tools panel (Figure 4-21) lets users add annotated markers and notes to the workspace, as well as create and relate information objects (activities, people and items) on the view workspace using diagrams, lines and colours. In this way, the panel acts like a semantic drawing toolbar, with tools for notes, keyword anchors, symbols and icons, action markers, grouping shapes, information object shapes, line diagramming tools and a colour palette.

Annotations and document holding: Users can write and view annotations for information items, workspace markers and the view itself in this panel (Figure 4-21). Important documents associated with a view can be dropped into the holding area. Documents in the holding area would also appear in other views, e.g.

universe view and goal view, as they are flagged as important. Each activity (and associated views) has its own holding area.

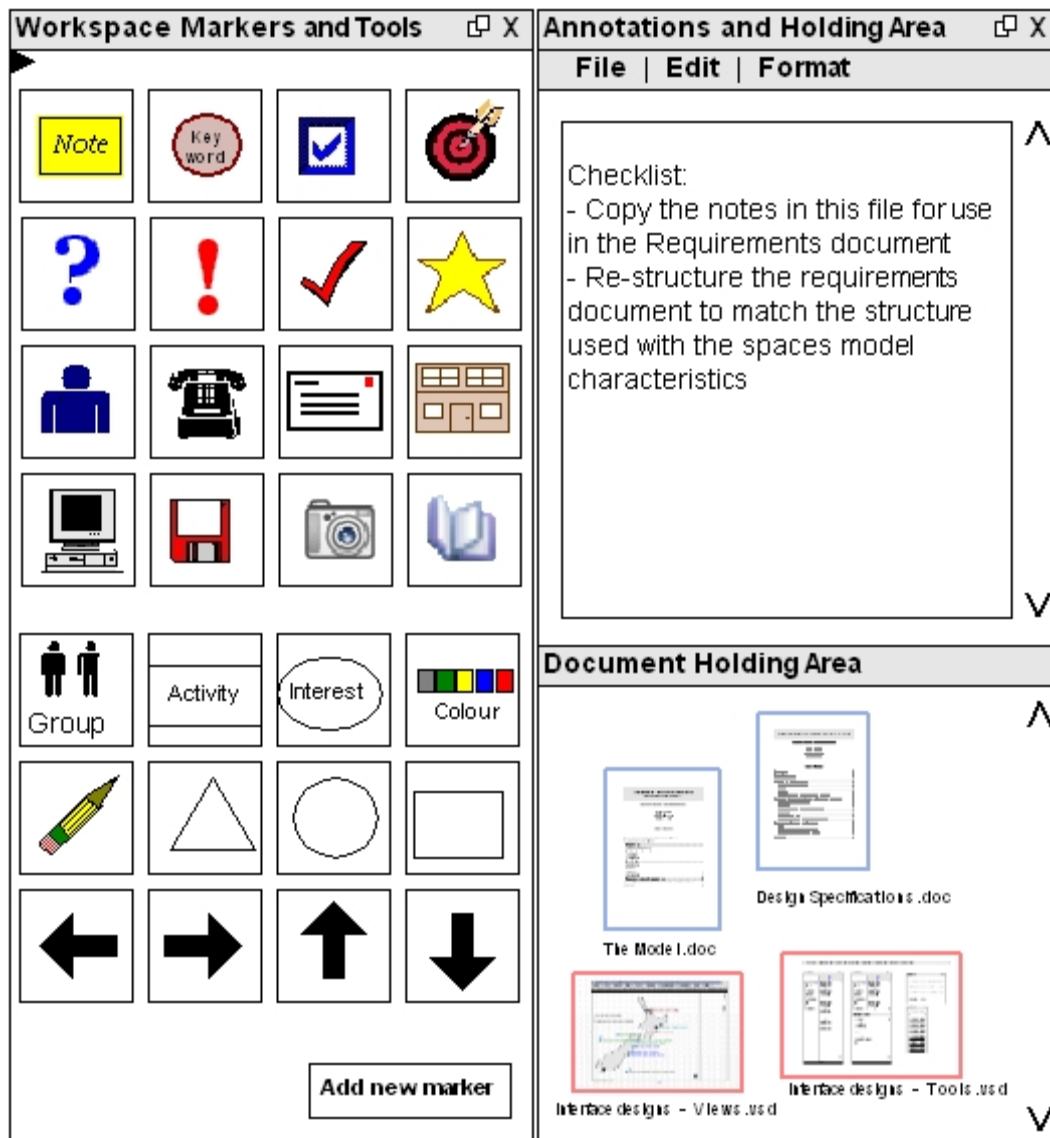


Figure 4-21: FlexTools Panels - Workspace Markers and Tools, and Annotations and Holding Area.

Information options: The information options panel (Figure 4-22) provides users with details of any information item they select on the view workspace, options for sharing views with others, as well as options for archiving information. In sharing views, users can select a view and select how much of it gets shared (e.g. the view can be shared in full with all documents, as an interactive view without the underlying documents, or as a view image for reference purposes). The panel

allows users to archive select information from their collection or their collection in entirety to a specified location, either with or without all the contextual detail.

The image shows two side-by-side panels from a software interface. The left panel is titled 'Information Options' and the right panel is titled 'Settings and Preferences'. Both panels have a close button (X) in the top right corner.

Information Options Panel:

- Item details:** A text box containing: File Title: Science and Space.htm, File Size: 20 KB, File Type: HTML, Date Modified: 6/10/2005, Date Created: 6/10/2005, Author: CNN.com, Source: WWW.
- Share view:** Includes a 'Select person or group' dropdown (Selected), a 'Select view' section with radio buttons for 'Share current view' and 'Share view' (Selected), and a 'Sharing options' section with radio buttons for 'Full view with all underlying items' (Selected), 'Partial interactive view without items', and 'View reference image only'. A 'Share view!' button is at the bottom.
- Archive information:** Includes a 'Select level of detail' section with radio buttons for 'Information items and all details' and 'Information items only' (Selected), and a 'Select information to be archived' section with radio buttons for 'The entire information collection' (Selected), 'Information from views' (Selected), and 'Information from activities' (Selected). 'Browse Location' and 'Archive!' buttons are at the bottom.

Settings and Preferences Panel:

- Your details:** Includes text boxes for 'Name: Lisa' and 'Login: *****', and an 'Edit your details' button.
- Adapt information to devices:** Includes a 'Select device' dropdown (Selected), a 'Switch synchronisation' section with radio buttons for 'On' (Selected) and 'Off', and a 'Synchronise information' section with radio buttons for 'Full (standard) with all items' (Selected), 'Selected items and item summaries', 'Item Summaries', and 'References to items only'. An 'Apply!' button is at the bottom.
- Information monitoring:** Includes a 'Switch information monitoring' section with radio buttons for 'On' (Selected) and 'Off', and a 'Monitor locations' section with a '(Filter terms)' text box, a 'Browse' button, and two checked checkboxes for 'C:/My Documents/' and 'C:/Documents and Settings/Lisa/...'.
- Infomesh appearance:** Includes 'Format font' and 'Format screen colours' buttons.

Figure 4-22: FlexTools Panels - Information Options, and Settings and Preferences

Settings and preferences: In the settings and preferences panel (Figure 4-22), users can edit their personal details and change the way InfoMesh looks and behaves. Specifically users can choose how InfoMesh adapts and synchronises information to devices, by switching synchronisation on or off, and selectively choosing to only synchronise minimal detail (e.g. item summaries instead of an entire document, or references to items only) to devices like PDAs. Users can likewise turn information monitoring on or off, and select which folders get monitored for information use.



Figure 4-23: FlexTools Panel - Activity Browser

Activity browser: Finally, the activity browser panel (Figure 4-23) provides folder-like access to activities and views. Users can select an activity to access its views and most recent queries. Activities are presented with their colour coding intact, and can be ordered alphabetically, according to access chronology or by related area of interest. Using the ‘list’ and ‘view’ options in the panel, users can either see view content or query results as a list (as shown in the figure) or select an item to display the corresponding context view or highlighted query results view. The document list shown in the figure is similar to the one displayed when executing a query and viewing the results as a list. Users can open an item directly from the list or select it to have the item highlighted in the view.

InfoMesh designs further support a range of toolbars (standard and view specific), menu bars, context menus, application dialogs, and application help documentation. The various designs presented before display some of the application toolbar designs. InfoMesh menu bars mirror many of the options provided by the context menus, toolbars and FlexTools.

Context menus are provided for the workspace (e.g. for adding more pockets, adding a note to the view or adjusting timeline granularity) and vary with the type of view or view segment. They are also provided for information items (e.g. for renaming, deleting and moving items, colour-coding items and adding annotations) and workspace markers (e.g. deleting, editing, annotating and colour-coding markers).

InfoMesh provides a variety of application dialogs. Of interest are dialogs for creating and setting properties for activities and other contexts such as devices, people and so on. There are also dialog windows for updating user details, formatting application appearance, specifying contextual details, and adding and setting properties for workspace markers.

4.2.3 INTERACTION DESIGN

The background research, the conceptualisation of Pervasive Personal Information Spaces and early focus group interviews, looked at user interaction needs and the forms of interaction that would support a wide variety of users, as well as the kinds of visualisation and interaction issues apparent in the daily use of electronic information spaces (as with accessing, retrieving, navigating and manipulating information). Here we now look at the interaction aspect of designing for InfoMesh to emphasise certain behind-the-scenes design choices and to illustrate interaction separately from the InfoMesh interface.

Interaction in InfoMesh takes into account a variety of direct and indirect interaction styles. Direct styles include direct manipulation, application feedback and multi-modal interaction. Indirect styles look into agents for automated functions and services, and adaptability and intelligence in the interface. The goal is to design an interaction experience that is as natural, non-disruptive and appropriate as can be for the different devices that InfoMesh would be used for.

Direct manipulation: InfoMesh design focuses heavily on direct manipulation to support user information interaction. As InfoMesh supports different devices (at this point desktops, laptops and PDAs), direct manipulation can be through the use of keyboard, mouse, stylus or touch screen. The interaction supported in InfoMesh through direct manipulation includes the following:

- Manipulating information objects, which allows users to select, move (e.g. items on the workspace), drag and drop (e.g. important documents into the document holding area), relate (e.g. through the diagramming tools), annotate and illustrate (e.g. using workspace notes and markers), bring up details for and open items.
- Accessing menus (including context menus), tools and options for manipulating and altering the application, views and information objects.
- Navigating the views through a pan and zoom functionality, overview windows and navigation buttons (e.g. going back and forward through previously visited views and navigating within a view).
- Querying and filtering the information space through dynamic queries, search and filter terms, and options.

Application feedback: Application feedback in InfoMesh design seeks to be minimally intrusive and mainly focuses on the following areas:

- Informing users about system status, especially when information is being loaded or saved to the repository, when information is being synchronised with another device, and when the system is processing a change to the view according to the use of FlexTools (e.g. by performing queries, applying filters, and changing contexts and visualisation styles).
- Dealing with errors, especially with respect to problems synchronising due to connectivity issues or data problems (e.g. duplicate or missing files).
- Providing clear and appropriate messages or visual feedback to present information, denote progress, and indicate outcomes of user action.

Multi-modal interaction: Although at present InfoMesh designs do not include multi-modal interaction, some ideas have presented themselves for using different modes in perceptualising the information space other than using the visual cues alone as provided by the views. Some ideas include audio labels and sound

identifiers for different information objects in the view, and ‘aural sweeps’ that use sound to indicate the information landscape. For example, with an aural sweep of the Universe View, one might associate dense segments of the information space with subdued high, continuous beeps and sparse segments with subdued low sound. The audio label of any significant information object may be played when encountered on the path.

Agents: Agents in InfoMesh provide a variety of behind-the-scenes services. They are designed to track user and device details, monitor information use, register and integrate user context, build and manage the information repository, adapt and format information to suit the relevant devices, process and adapt information according to FlexTools settings, generate visualisations on the fly, manage device sessions and synchronise information with other devices. They work around the user’s context, taking over some of the user’s complex and time-consuming tasks.

Interface adaptability and intelligence: InfoMesh is designed to adapt to the device in use and its capabilities (including view, interaction and information restrictions), and user preferences for application appearance and behaviour. As InfoMesh is designed to track information usage and relate items to one another and to specific contexts, the system can be designed to learn from the user’s information-interaction and provide elementary help in clustering information on workspaces, and associate new information items with the appropriate activity.

4.2.4 DESIGN RATIONALE AND THE DESIGN SPACE

Existing designs for visualisations are generally founded on a single or limited combination of user contexts, mostly the information context; selected models of information visualisation, organisation and interaction (e.g. spatial overviews supporting direct manipulation); and the information activity or activities of relevance (e.g. searching and browsing, word processing).

In this research, the visualisations designed are for accessing and viewing information across devices according to use context. As this is very much a new area, it’s difficult to say if the design space chosen is the best. However, in

designing for Pervasive Personal Information Spaces a variety of guidelines have been observed to provide appropriate design choices for ubiquitous computing over existing designs used for single-device personal computing.

The conceptualisation of Pervasive Personal Information Spaces as well as the actual designs for InfoMesh are based on several user and activity-oriented frameworks to better support user information interaction in the ubiquitous computing environment. The various frameworks and theories (reviewed in section 2.2) support and inform the focus on:

- scaling interaction with respect to time, devices and people (Everyday Computing),
- user activities and work contexts (Everyday Computing, Activity Theory),
- device integration, user interaction experience and support for the breadth of activities in user information interaction (Framework for Developing Personal Information Appliances),
- navigating an integrated and personalised information space (Navigation of Information Space), and
- subjectively classifying and contextualising items in the user's information space (user-subjective approach to PIM systems).

Flexible views indicate the use of views that can be altered to suit the user and use context. As such, flexible views in InfoMesh are designed to support multiple devices and user contexts, multiple models of information presentation and organisation, and a number of interaction styles. As flexible views aim to support access and visualisation of personal information spaces, the activities supported include information access, exploration, browsing and searching. Information gathering, generation, communication and collaboration are also supported to a certain extent within the user's personal information space context. Examples for supporting some of these include:

- Contexts of use (see section 3.2.1): devices used (desktops, laptops and PDA's), locations of use, people involved, activities undertaken, information accessed and manipulated, information relationships, user goals and tasks, and time frames. Flexible views can provide views according to a single context (e.g. information organised according to activity) or a versatile combination of

contexts (e.g. temporal organisation of information used according to device and location, such as laptop and university).

- Models of information presentation and organisation (explored in sections 2.5.1 and 2.5.2): many of these can be applied singly or in combination by using FlexTools to manipulate the views. They include:
 - activity, social, location or time-based models (e.g. single context views such as a view displaying information accessed at a particular location),
 - spatial, hierarchical, network and temporal organisation (e.g. information associated with the members of a group in a network visualisation), and
 - overview, pan and zoom, focus + context, detail-on-demand, filter, relate, history presentation styles (e.g. a device based view filtered by time).
- Interaction styles (explored in section 2.5.3): direct manipulation (e.g. re-clustering information objects in a view), adaptive techniques (e.g. adaptation of information and visualisation to device), personalisation and customisation (e.g. saving views and FlexTools settings), autonomous agents (e.g. agents used for monitoring directory changes, adapting information to device).
- Information activities (explored in sections 2.3.2 and 2.3.3): information browsing is supported using overviews and flexible views, searching is supported using filter and query windows, and information sharing and collaboration by sharing views and selected view contents for example.

Designs further build on existing user experience (with desktop and folder metaphors, and direct manipulation) as well as a variety of learning styles and user intelligences, models of user memory as well as familiar mental models (reviewed in section 2.3.1) to take full advantage of flexible views. As such the designs are aimed to provide rich contextual and associative models of information visualisation and access. Examples for supporting some of these different abilities and models include:

- Prior user experience: Desktop and folder metaphors, direct manipulation and so on (e.g. thumbnail representations of information objects, drag and drop facilities).
- Learning styles: innovative (e.g. ad hoc creation of views to suit the user and context, personal history of information use), analytic (e.g. use of activity

histograms and relationship views), common sense (e.g. activity views and map views) and dynamic learning (e.g. view sharing and flexible views).

- User intelligences: symbol-related (e.g. using icons, action and landscape markers), person-related (e.g. relating information to social contacts) and object-related intelligences (e.g. use of thumbnails and context oriented views, such as location and device based views).
- Models of memory: semantic (e.g. information associations and action markers in views) and episodic memory (e.g. personalised temporal and activity views).
- User mental models and perception: semantic navigation of information space (e.g. use of markers to identify user actions and the changing information landscape), associative and perceptual organisation of information (e.g. clustering and colour coding information objects) are some examples.

The variety of ad hoc visualisations that flexible views give and their adaptability to user and use context sets them apart from other systems and makes them especially appropriate for study within the area of ubiquitous computing.

The view designs presented so far are the designs selected for detailed investigation in the design phase, from the various designs and design alternatives explored during earlier paper prototyping. With each phase, from the conceptualisation of Pervasive Personal Information Spaces to the conceptual and physical design and implementation of InfoMesh, the design space has been explored, studied and finally narrowed. The final design choices and trade-offs made for implementation can largely be attributed to:

- 1) Design appropriateness: selecting designs and design elements that satisfied analytical evaluation including the persona-based test tasks,
- 2) Feasibility: selecting a smaller set of designs that could be implemented within the time-frame and technological limitations, and
- 3) Evaluation appropriateness: selecting the core designs that would best help assess the underlying framework and test out the hypothesis through user evaluation.

The designs selected for implementation start off with several work views (namely the work view, overview and notice board), specific pre-set context views (namely activity, social and map views), and basic 'advanced' views (for incorporating

multiple contextual elements). These views are all supported by FlexTools, where view display, query and filter, contexts, annotations, and other options are made available with some constraints.

4.3 INFORMING DESIGN: PERSONAS, SCENARIOS AND ACTIVITY SNAPS

InfoMesh requires a unique, rich and interactive interface to support flexible views and a detailed information structure for modelling the underlying information relationships. This necessitated the use of an array of tools and methodologies to inform InfoMesh design and development. Of special interest is a set of design tools, comprising of personas, scenarios and *activity snaps*, which is used to effectively translate the formulated requirements, and then to inform, evaluate and refine InfoMesh design.

Activity snaps were developed progressively in this research to support InfoMesh development. The interactive and information-rich environment for Pervasive Personal Information Spaces needed support to bridge the gap between requirements and design, beyond that provided by personas and scenarios of use. Activity snaps build on user activities obtained from personas and specific scenarios, and have shown themselves to form a powerful design tool. They bring realistic user activity ‘data’ into the design phase and the designs themselves, and their use carries on past the design phase into InfoMesh prototyping and evaluation. User actions, information use and work context from the activity snaps bring visualisation and interaction issues to light, and inspire presentation ideas and ways of interacting with InfoMesh that are use appropriate.

Here we take a look at the tools and methodologies used in this research, with an emphasis on the use of personas and scenarios. We then consider activity snaps in detail, how they fit in with the use of personas and scenarios, and how they are constructed and used to support a progressive design and development process. Examples from the research work illustrate their use in the development of InfoMesh.

4.3.1 TOOLS AND METHODOLOGIES

Various design, development and evaluation tools and methodologies supported the work in this research from conceptualisation to user evaluation. An evolutionary and adaptive, iterative development methodology supported by user centred design techniques (Dix *et al.* 1998, Larman, 2003) was central in developing the Pervasive Personal Information Spaces concept. Accordingly, the development cycle included several iterative phases (including conceptualisation, requirements analysis, interface and interaction design, system design, implementation and evaluation) where the output or specifications from the phases evolved and were refined over each of the iterations. Tools and techniques used here included:

- User experience design, whereby a focus group study, personas, scenarios and activity snaps supported conceptualisation and development of Pervasive Personal Information Spaces as well as designing the user experience.
- Paper prototyping, assorted paper-and-pencil and VISIO mock-ups representing various alternative task, information, interface and interaction designs, working from requirements, scenarios and activity snaps.
- Object-Oriented modelling and design, to support system design and develop the information and system architecture.
- Iterative prototyping, as a foundation for the InfoMesh system, presenting the features and functionality developed through the paper prototypes and architecture specifications.
- Analytical evaluation, to evaluate design mock-ups and early prototypes using heuristic evaluation and interface walk-throughs with the aid of activity snaps.
- Structural and functional testing, for revising and refining prototype functionality.
- User-based evaluation, to gain user insight through studies carried out at various stages of development of both chauffeured prototypes and a functional prototype system using exploratory, assessment, comparison and user-subjective tasks.

As Pervasive Personal Information Spaces emphasises personalising user information-interaction, the tools for designing the user experience held an

ongoing function within the development process. They were adapted and expanded on throughout the research work to develop InfoMesh interface, interaction and functionality:

- Focus group study (following suggestions presented by Silverman (2000) for mini-group interviews, see Appendix A), to support persona and scenario development, gain insight into the problem space and elicit user views on early concepts and models.
- Personas, as a starting point and reference for understanding and fashioning the user information-interaction experience.
- Scenarios, for exploring user activities and as a foundation for designing functionality and interaction.
- Various snapshots, to visually capture user information spaces, work contexts and activities, which were then used as view content to support design and evaluation:
 - Information space snapshots, which pictorially summarise the activities and activity relationships that make up a persona's information space.
 - Context snapshots, which consist of storyboards with an explanatory scenario that help understand user activity context and form the starting point for developing activity snaps.
 - Activity snaps, to support interface, interaction and information design, through to analytical and user-based evaluation, by utilising realistic activity data in the various designs and prototypes.

Among these tools, activity snaps (and the underlying personas, scenarios and context snapshots) played a vital role in the conceptualisation of Pervasive Personal Information Spaces and the progressive design, development and evaluation of InfoMesh. Activity snaps are developed from the initial creation of appropriate personas and scenarios. Consequently, it is important to understand their background and use in this research work first.

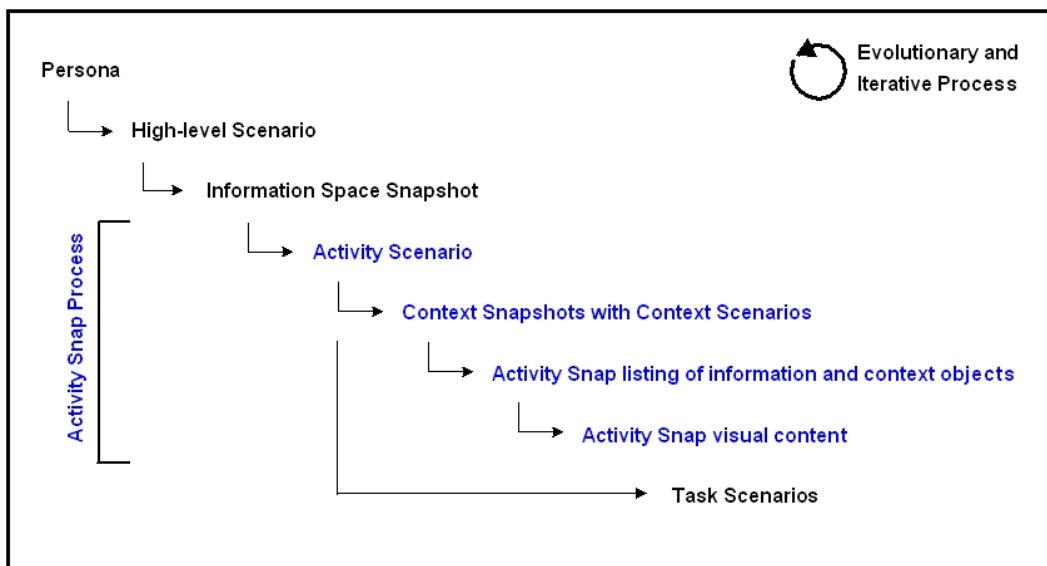


Figure 4-24: Persona, Scenario and Activity Snap development

Together personas, scenarios and activity snaps have influenced and informed the use of many of the other tools and methodologies in this research. Figure 4-24 presents the ordered and iterative process of creating these design artifacts, as they are discussed in the following sections. The process is evolutionary as personas, scenarios and activity snaps are refined and updated throughout the development process, especially as each design artifact aids in understanding the other better (with respect to, for example, content, detail and perspective).

PERSONAS

Goodwin (2001) defines a persona as “*a user archetype you can use to help guide decisions about product features, navigation, interactions, and even visual design*”. Personas portray fictional user archetypes that are representative of specific user groups in the target population (Brechin, 2002). They incorporate specific user characteristics, goals, usage and behavioural patterns. In conceptualising Pervasive Personal information Spaces, personas help concretely present examples of users and their information-interaction in the domain of personal information spaces and the ubiquitous computing environment.

In this research work, personas stem from preliminary focus group interviews, observations and discussions, which go a little way towards the use of detailed interviews, field studies and so on required in accurately identifying representative users, as advocated by Grudin and Pruitt (2002). An approach that includes the

use of statistical methods, such as Principal Components Analysis (PCA) used by Sinha (2003) and Factor Analysis as used by McGinn and Kotamraju (2008), would be more appropriate and beneficial to help develop personas, which reflect back appropriately to the user domain and real user goals, information interaction and needs. Further interviews and observation would then help revise and validate these personas (Sinha 2003, McGinn and Kotamraju 2008).

The interviews, observations and discussions around computer-supported work considered users and user groups, activities, device use, current problems and frustrations. The focus group interview for example brought the following to light:

- the large variety of computer-supported activities people carry out,
- the difficulty and effort in remembering previous work states and resuming work,
- the difficulty in remembering and locating information items, especially after some time has passed, and on different devices,
- the lack of meaningful links or relationships between information items,
- the effort and issues relating to information synchronisation when interacting with multiple devices,
- the overhead of information management that detracts from actual work,
- the reality of adapting natural behaviour to fit with the technology and interaction available,
- the need for anytime-anywhere access to personal information, and
- the wish for a 'lifelong diary' of information use to revisit effortlessly.

The computer-supported work people engage in proved to be very varied. An example set of computer-supported activities observed and discussed with users include:

- researching and writing up presentations for work,
- looking up and studying drawing techniques, creating digital art and setting up a portfolio,
- developing an idea for a small business and investigating its set-up,
- researching e-book design and online publishers, and
- exploring real-estate online for investment purposes.

Users classified their work in several ways in the focus group study and discussions, specifically as professional, study or personal, and at a second level, according to the application or function (such as Calendar or Word). Observations however showed their work to be part of activities, and the information-interaction (e.g. gathering and searching information, writing, designing graphics and so on) implicitly recognised and understood by users as part of these activities.

Several provisional personas were built using these details and sketching out user needs, characteristics and behavioural patterns (Goodwin, 2001 and 2002). These personas were described to emphasise certain activities and usage patterns, even though the target user population would overlap greatly in their real world activities (e.g. most people would have activities relating to shopping, study, hobbies or social interests). The resulting personas and emphasised activities included:

- Lisa, a busy student: study activities and social interests,
- Aran, a motivated artist: creative, evolving, open-ended activities,
- Mijke, a career mum: work-related activities and family management activities such as tracking finances, trip planning, and online shopping, and
- Jason, an active teen: social, online activities and hobbies.

Lisa and Aran provided most of the scenarios and activity snaps used in the design and evaluation phases, with the remaining personas and user activities acting as a background reference for different perspectives on InfoMesh use. (Lisa and her activities were presented in the previous section and Aran will be introduced in the next chapter on the InfoMesh system.)

In the current research, the process of developing and defining personas (as well as scenarios) was adapted to particularly emphasise and clarify user activities, work context (e.g. social and physical), multiple personal devices, information use and needs, individual information behaviour and preferences, user roles, goals, and issues. As such all these personas have proven to be truly engaging and sufficiently real (Grudin and Pruitt, 2002), to support the development process and the creation of realistic scenarios, context snapshots and activity snaps. As a result, they form part of the user experience design process employed here, augmenting several other tools (Pruitt and Adlin, 2006).

SCENARIOS

Rosson and Carroll (2001) describe a scenario as “*simply a story about people carrying out an activity*”. They differentiate between various types of scenarios, including problem scenarios, usage scenarios, user interaction scenarios and design scenarios. Rosson and Carroll explain that scenarios depict actors, goals, supporting tools and other artifacts, as well as user thoughts and actions and how users work towards their goals. Carroll (1999) further describes how scenarios can be created at multiple levels and from several perspectives, providing high-level, cognitive, functional or system views for user tasks.

In the research into Pervasive Personal Information Spaces, scenarios are created at multiple levels. However, instead of focusing on tasks and low-level usage, the scenarios here start at a high or abstract level to first consider the context of a persona’s activities, activity relationships, use contexts and goals (as seen in the scenario depicting Lisa’s activities related to NZ wines and vineyards in section 3.2.2). These high-level, exploratory scenarios accordingly present both the virtual and real-world elements of the user’s activities.

At the second level, the exploratory scenarios form the basis for activity scenarios (i.e. a scenario that follows a single high-level user activity) that tracks simple interaction details alongside information about the persona’s context (e.g. social and physical). As such, the activity scenario functions as a tool to understand information use and interaction within the context of a rich user-specific activity (e.g. Lisa’s “Newsletter” activity in section 3.2.2) as opposed to a more generic, lower level task. In the conceptualisation and design phase, the activity scenario helps emphasise user experience rather than sequences of user action. At later stages in the development process, the activity scenario can indeed make way for usage scenarios and use cases, taking a more functional or system view to support lower level interaction and system design.

Activity scenarios (like Lisa’s “Newsletter” activity scenario) also double as high-level problem scenarios. They assist with understanding current issues in the user domain, but are abstract enough to be transformed into something akin to design scenarios to convey new ways of interaction (as explored in section 3.2.2 and Appendix section D.1 when discussing Pervasive Personal Information Spaces solutions now and in the future). The sections mentioned also indicate an interesting example of this use by presenting new ways of interaction according to

current feasibility and future possibilities. The future scenario in Appendix section D.1 allows developers to keep future ideals and goals in mind, while subtly inspiring and directing the design process for the present. The future scenario also makes it easier to adjust the development process towards those long-term objectives as they become feasible.

At the last level, activity scenarios can lead to several task scenarios. These are short and simple interaction scenarios or scenarios of use that are employed during design and prototyping to clarify particular system requirements and functionality, or more specifically, to act as test tasks for the persona. They focus on the persona's task objective and the action sequences used to achieve the objective.

The scenarios in this research transcend the scenario-based design process (SBD) (Carroll, 2002, Rosson and Carroll, 2001) as they are based on personas (Cooper and Reimann, 2003) and form the basis for further design artifacts. Both personas and higher-level scenarios have supported the conceptualisation of Pervasive Personal Information Spaces and design brainstorming, working as tools in "*solution-first design*" (Carroll, 2002) that in part helped envision nebulous elements of the concept before having to define these fully.

INFORMATION SPACE SNAPSHOT

Persona descriptions and the corresponding high-level scenarios give a glimpse into each persona's information space. An information space snapshot sketches out this information with simple supplementary and pictorial details of the persona's activities during a set time period.

A working **definition** of **Information Space Snapshot** is as follows:

An information space snapshot describes and/or illustrates simple details of a persona's various activities that encompass his/her information space and information-interaction during a set time period. The snapshot can include details such as activity titles, start and end dates for activities, activity relationships, and usage and interaction frequency or intensity. Consequently, information space snapshots provide background context for the activities selected to inform the development process through activity scenarios, context snapshots and activity snaps. Details from an information space snapshot can directly map onto visualisation content for overviews of the persona's information space.

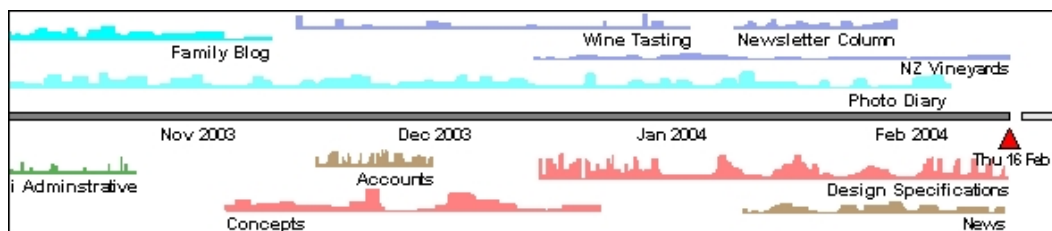


Figure 4-25: Visual information space snapshot for Lisa

For example, Lisa’s information space snapshot would include details of her Newsletter column as well as some of her other study, research and hobby activities. Figure 4-25 provides a visual representation of Lisa’s information snapshot for a period of several months, as used in a visualisation in the design section. The snapshot provides an overview of Lisa’s information space for the given time-period as well as more detailed context for the particular activities of Lisa’s that are explored through activity snaps. This context adds realism and exposes activity relationships in the persona’s work that can be useful in the development process.

CONTEXT SNAPSHOTS

Activity scenarios are the first stage of creating activity snaps. At the second stage, activity scenarios are elaborated using simple context snapshots and corresponding context scenarios. Context snapshots bridge the activity scenario with the full-fledged snapshot of the user’s activity.

A working **definition** of **Context Snapshots** is as follows:

Context snapshots are storyboards depicting the user’s use context at specific times during a selected computer-supported activity. They pictorially present, relate and describe the pertinent contextual objects at the given time of the user’s activity, from each of the seven contexts in information work. These contextual items include elements from both the virtual and real world aspects of the user activity, and are annotated further with user actions. Each snapshot is supplemented with a descriptive context scenario.

So context snapshots are essentially storyboards of the user’s changing use context. Storyboards are used with scenarios at times (see Kantola and Jokela, 2007) to pictorially depict a scenario’s sequence of (inter-) actions for a user task. These pictures can contain various interaction, system and environmental cues. As with the activity scenarios however, context snapshots do not focus on a task, the

system or the sequences of action. Instead, they provide specific information about the user activity and the activity's context, by representing the pertinent contextual artifacts present, related actions and relationships at specific times during the activity (e.g. the context snapshots for Lisa's "Newsletter" activity presented in 3.2.2). They contain a colourful pictorial representation as well as descriptions of items from the seven contexts (people, related activities, information, locations, time, goals, devices and technology), along with actions taken and the transfer of information or knowledge. The context scenarios summarise the snapshots, to provide a supporting narrative.

To some extent, context snapshots resemble entity-relationship based analyses or techniques (discussed in Dix *et al.*, 1998). They include objects (e.g. information objects and people) and contexts (e.g. locations), actions (e.g. synchronising information) and events (e.g. visits or meetings), at the level and scope of a user activity. The snapshots can be used alongside the scenarios, as they have in this research, to support information, interaction and system design, and the object-oriented modelling process (see Rosson and Carroll, 1996 for the perspectives gained from object-oriented design derived from user scenarios). The principal focus of context snapshots however is in understanding and developing activity snaps.

4.3.2 ACTIVITY SNAPS

The interface, interaction and information design for information-rich interactive systems is highly dependent on the domain, specifically the users, user tasks and the underlying information represented. In the development of Pervasive Personal Information Spaces, as with explorations into novel visualisation and interaction paradigms, the concepts are too abstract to directly map onto design ideas or design elements. Accordingly, exploring, designing and evaluating new designs can prove a great challenge.

Current tools such as personas and scenarios help in making users and their information and interaction needs more transparent. Though these tools tackle users and their tasks (envisioned here at the level of user activities), the varied and user-specific information at the centre of the interaction is only portrayed partially. This information however, visualised and manipulated extensively in

Pervasive Personal Information Spaces, also affects the interface and interaction design choices. This is where activity snaps come in. They bring in user activity information directly into the development process to help design, refine and evaluate information presentation and interaction.

A working **definition** of **Activity Snaps** is as follows:

An activity snap is a detailed snapshot of an entire user activity with realistic activity, contextual and representational data that together form an annotated trail of information use and interaction. The underlying data can be real or simulated, and is based on an activity scenario written for a persona.

An activity snap has a textual and visual component, and develops and evolves in detail over the design, prototyping and evaluation phases. It is used to incorporate user activity data in design and prototype visualisations to help drive design, as well as evaluate and refine design elements, interaction and functionality.

In the previous section on interface and interaction design, activity snaps formed part of the view designs. They illustrated and revealed functionality and use, while behind the scenes, personas and scenarios helped give definition to the open-ended design space. Like personas and scenarios, activity snaps are simultaneously concrete and flexible as they inform system design and development.

DEVELOPMENT

The creation and use of activity snaps occurred naturally in the InfoMesh design phase to envision appropriate information-rich visualisations. They were developed on from there to enhance the InfoMesh prototyping and evaluation processes. As shown in Figure 4-24, activity snaps are created in several steps:

1. Create an activity scenario for a persona's selected activity, with work progress, interaction and relevant contextual detail (e.g. people, locations, devices), from the start to the completion or current state of the activity. For the creation of activity snaps, the activity scenario will largely conform to a design scenario and depict the envisioned user interaction, i.e. with the new interaction paradigm, system and/or technology.
2. Draw out simple context snapshots with supporting scenarios for several specific instances during the activity to understand the activity's use context. Context snapshots are especially important for complex activities. For simpler

activities, this step can be optional or reduced to rough sketches exploring the user's work context and contextual objects.

3. Create a listing of the information and context objects used during the activity. The activity snap listing is the textual component of an activity snap. This listing would become increasingly detailed through the development process.
4. Convert the listing into content for the designs or prototype, by pulling together the information and context objects, with the appropriate visual representational details for them. The activity content generated from the activity snap listing is the visual component of an activity snap.

In the early stages when starting work on interface design, the activity snap listing and content do not have to be complete or fully precise to be useful. Both the activity snap listing and the visualised sample content however evolve with more detail as the system development progresses from design to prototyping to evaluation.

Creating an activity snap listing

Steps 1 and 2 have been detailed before, with an example presented in section 3.2.2 for Lisa's "Newsletter" activity. Here we'll look at step 3 for a simple activity, namely Lisa's "NZ Vineyards" activity managed with InfoMesh, which looks at various web-sites Lisa has bookmarked for tracking NZ vineyards, and reviewing and shopping for wines.

Activity scenario for "NZ Vineyards" activity

Lisa has recently started to use the InfoMesh system on her desktop, laptop and PDA. She wants to track several activities (relating to her study as well as her interests) in InfoMesh through matching views.

Lisa first creates an activity to manage bookmarks to the web-sites of various vineyards and wineries in New Zealand, as part of her interest in NZ wines and vineyards. As wines and tastes differ across New Zealand due to the location and type of vineyards usually found in certain areas in the country, Lisa sets up a map view for organising her bookmarks, her notes and photos. She feels that this way, whenever she means to visit an area or try out certain types of wines, she'd be better able to locate where to go and which web-sites to browse and shop at. From time to time, Lisa would also like to view the activity according to a chronological view to see where

she's at and what to plan for next.

Lisa tracks down various web sites of interest on her laptop over a couple of weeks and arranges them on an NZ map according to the vineyard location. She flips to the chronological activity view from time to time to add notes for some of the web pages she visits or shops at, the wines she's chosen for her wine-tasting group and how they were rated, or ideas for things to explore next. The map view also helps her when she's visiting a vineyard and carrying her PDA with her. She can use the view to retrieve details and reviews of the local wines and locate nearby vineyards she also took an interest in.

In generating an activity snap, all the necessary background details for the activity snap need to be recorded first, such as activity title, area of interest, start and end dates, matching visualisation and so on. Then an activity snap listing can be created.

In creating a listing of information and context objects for the activity, the format followed is to textually itemise information items with relevant, corresponding context details. Information items basically include the files created or accessed (e.g. documents, images, audio, video, web pages), bookmarks saved and URLs visited, emails sent and received, and so on. Contextual items relating to each information item in the activity snap listing can include the following information for each of the seven contexts in information work:

- Who: authored by, shared with and shared by...
- What: activity details (e.g. start-up date and area of interest), activities the item belongs to and related activities...
- Which: related information items (e.g. using colour-coding), details such as user actions, notes, events, importance, colour code, markers and file details...
- Where: physical device location of item, and real or virtual location (e.g. geographical, building and web) related to use, whereabouts or association...
- When: time of creation, access or modification...
- Why: related goals and milestones...
- How: devices the item is created or accessed on...

Many of these contextual details map to objects, such as the information items themselves (including notes and markers), the people authoring or sharing items, activities, locations, goals and devices. These objects and supporting details together form the activity content. The user domain, requirements and

visualisations at the centre of the development process dictate the information and contextual details designers should include in their activity snap listings. In including extra supplementary details, activity snaps can help in discovering further ideas, opportunities, possibilities and alternative options in the design process.

The “NZ Vineyards” activity focuses on items specifically connected to one main context, namely location. Secondary contexts include the temporal context indicating the evolution of Lisa’s activity interaction (e.g. relating to tracking sites and shopping over time), and the information context comprising of bookmarks, browsing trails, annotations and photos.

A partial activity snap listing for this activity now follows, with start-up details of information items (specifically web-site bookmarks) and contextual details for creating sample content for a preliminary view design in InfoMesh. These early listings are fleshed out during the design and prototyping stages, when they are converted to visual content.

Activity snap listing for “NZ Vineyards” activity						
<i>Activity Details</i>						
<i>Activity</i>	<i>Colour</i>	<i>Area of Interest</i>	<i>Start Date</i>	<i>View</i>	<i>Map</i>	
NZ Vineyards	Violet	Interests	20-02-2006	Map	NZ Outline	
<i>Information and Context Details</i>						
<i>Title</i>	<i>Geographical Location</i>	<i>Device Path in Repository</i>	<i>Date Created</i>	<i>Colour</i>	<i>Priority</i>	<i>Notes</i>
Alana Estate	Martinborough	Laptop C:\Documents	21-02-2006	red	Normal	
Bentwood Wines	Canterbury	Laptop C:\Documents	23-02-2006	blue	Normal	
Black Ridge Vine	Central Otago	Laptop C:\Documents	02-03-2006	purple	Normal	
Cairnbrae	Marlborough	Laptop C:\Documents	20-02-2006	green	Normal	Last wine
Fairhall Downs E	Marlborough	Laptop C:\Documents	20-02-2006	green	Normal	
Forrest Estate Wi	Marlborough	Laptop C:\Documents	20-02-2006	green	Normal	Last wine
Guided wine tour	Central Otago	Laptop C:\Documents	03-03-2006	white	Normal	
Kahurangi Estate	Nelson	Laptop C:\Documents	20-02-2006	green	Normal	
Kaikoura Wine C	Kaikoura	Laptop C:\Documents	23-02-2006	blue	Normal	
Kaimira Estate	Nelson	Laptop C:\Documents	20-02-2006	green	Normal	
New Zealand Vin		PDA C:\Documents	05-03-2006	white	High	Excellent
Odyssey Wines	Marlborough, H	Laptop C:\Documents	27-02-2006	white	Normal	

Palliser Estate W	Martinborough	Laptop C:\Documents	21-02-2006	red	Normal	
Pegasus Bay Win	Canterbury	Laptop C:\Documents	23-02-2006	blue	High	
Riverside Wines	Hawke's Bay	Laptop C:\Documents	27-02-2006	turquoise	Normal	
Rossendales Win	Canterbury	Laptop C:\Documents	23-02-2006	blue	Normal	
Seresin Estate Lt	Marlborough	Laptop C:\Documents	20-02-2006	green	Normal	Last wine
Soljans Estate Wi	Auckland	Laptop C:\Documents	27-02-2006	burgun	High	
Sunset Valley Or	Nelson	Laptop C:\Documents	20-02-2006	green	Normal	
The Grape Taste		PDA C:\Documents	05-03-2006	white	High	
Tiri Tiri Organic	Gisborne	Laptop C:\Documents	27-02-2006	turquoise	High	
Villa Marla Estate	Marlborough, H	Laptop C:\Documents	27-02-2006	white	Normal	
Waiheke Wines	Waiheke Island	Laptop C:\Documents	27-02-2006	burgun	Normal	Ask about

This listing would be detailed further with for example file details, preview thumbnails, all access dates for the various vineyard and review sites over time, and other annotations. Tracking the user activity through continuous use (and so gathering access dates and ongoing annotations) is important. Chronological views of the user's activity require this information to accurately present the user's information trail, with the changing information contexts, user behavioural patterns and activity evolution. Here the listing serves as a simple example.

Activity snaps are tailored with the information necessary for the visualisations they help develop. This activity snap listing was converted into sample content for a 'Map View' in InfoMesh, presented earlier in section 4.2.2.

The activity snap listing for the "NZ Vineyards" activity is a simulated activity snap. Essentially the activity content captured by an activity snap can be real or simulated, to generate a realistic trail of information use. In creating simulated activity snaps, developers can apply the following methods to capture content for the listing:

- Carry out an activity created for a persona - in the role of the persona - and log the information trail, adding further contextual details (*method 1*). This mainly involves gathering, creating, annotating and communicating information for the activity, without extraneous detail such as creating the actual content of the documents (e.g. such as the newsletter column in Lisa's "Newsletter" activity).
- Take an existing activity's information items (e.g. the activity of preparing a presentation with supporting research material and notes) and re-create the

activity. Map an activity scenario and activity snap to this activity's information with appropriate, additional contextual details (*method 2*). The activity can belong to a user or even a member of the development team.

Though these activity snaps are realistic, they are not real. In creating activity snaps that are based on real user information trails, the only method is to track and log a user's actual information trail for a specified activity, with supporting contextual details (*method 3*). User activity can be observed, electronic information trails tracked on their devices, and contextual details added from observations and user logs or notes. It is important for both simulated and real activity snaps, that the activity and information trail correspond to the persona it's related to and his/her behavioural patterns and preferences.

In this research work, all three methods of capturing activity content have been employed. The activity snap listing for the "NZ Vineyards" activity was generated using the first method.

Converting an activity snap listing into view content

Once an activity snap listing is created, the next step (step 4) is to employ it to generate content for the design and prototype visualisations. This visual content and the underlying textual listing mature as they are incorporated into the designs and prototypes, as details that are as yet incomplete, missing or ring untrue become apparent.

The steps for converting the activity snap listing to content for designs are as follows:

- a) Select a segment of the listing for representation, appropriate for the visualisation and within the confines of a design mock-up. This can for instance involve selecting a specific time for a chronological view, or a sub-set of spatial information for spatial map views.
- b) Convert the activity snap listing's contextual detail for the selected activity segment into appropriate visual object representations according to the visualisation. This may for example involve mapping information items to thumbnails and titles with colour and grouping, location information to maps, people information to photos and names, actions into markers or symbols, time into textual and interval representations, and so on.

- c) Design or generate any of this necessary representational data, such as the thumbnail previews of the information items, maps, markers and so on.
- d) Depict the information items and contextual details in the design utilising the representational data, with appropriate item arrangement.

Essentially, in going through these steps, the activity snap listing helps to first map out the information design for the visualisation and the design of view content elements, and then to refine and improve them.

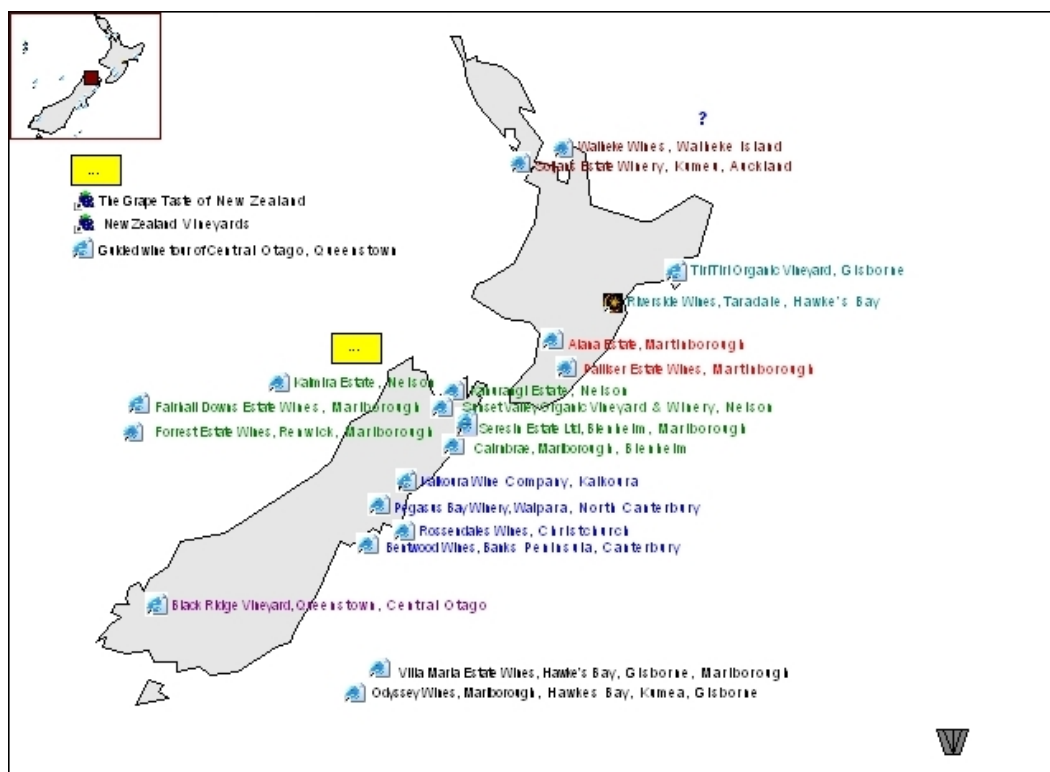


Figure 4-26: Map View design with activity snap details for the "NZ Vineyards" activity

For the “NZ Vineyards” activity, the design visualisation with the activity snap content is presented in Figure 4-26 (the design was also presented with further detail in the previous interface design section). In this design, the selected segment corresponds to the entire spatial context, as the design is for a ‘Map View’. The design represents information items by their icons and titles, with colour coding, some workspace notes, and item arrangement according to location (or outside of a specific location if the items have no geographical associations or require special emphasis from the persona’s point of view).

In the prototyping stage, the activity snap content is developed to support the entire user activity, i.e. the content now spans the entire activity context (e.g. time

and space) rather than just a segment so as to present the complete, interactive and navigable activity snapshot. The following steps accomplish this process:

- e) Create any further representational data, such as thumbnails and maps.
- f) Generate the visualisation with the activity content. As visual representations have already been designed for the various information and contextual objects and built into the prototype, the main step now is to generate the content in the corresponding prototype visualisation. In InfoMesh prototyping, this was carried out using an '*activity snap generator*'. This module effectively takes activity snap listings as data sets (as files, with necessary icons, thumbnails and maps etc.), and generates the corresponding visualisations from the given details using the prototype's built-in objects.
- g) Survey and organise the activity snap visually with for example item grouping or placement. In this stage the designer/developer goes through the activity snap to move and group items to mimic the user's activity sessions, patterns of information use and information behaviour (e.g. positioning items near each other when they have been accessed together with a related purpose).
- h) Update the textual listing and the visual activity content with more contextual detail as the necessity of that detail becomes clear (e.g. annotations or item details). Basically, the designer/developer reviews the activity snap again, noting omissions or elements in the activity snap that are unrealistic and uses the prototype itself to change or add further details into the activity snap.

These steps assist with refining the activity snap, understanding and interpreting user activity content and evolution, perceiving how activity content is best presented in the interface, and specifically, improving the design and interaction elements to better support activity visualisation and work.

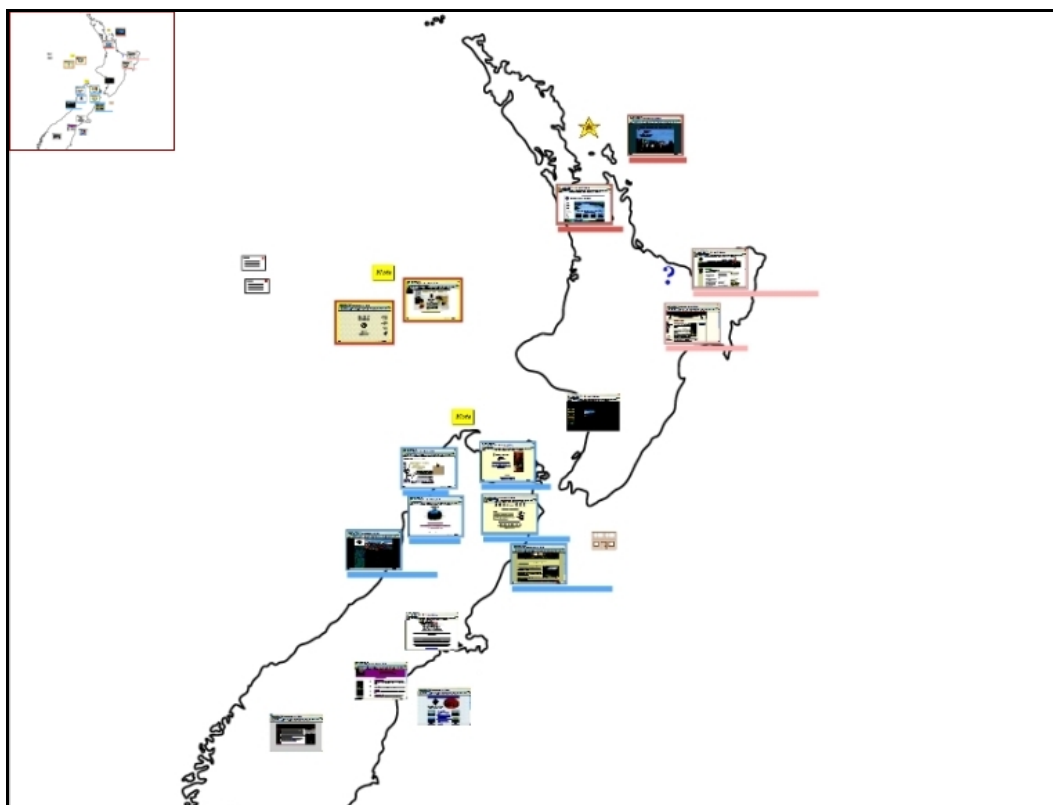


Figure 4-27: Prototype Map View using the "NZ Vineyards" activity snap, with user filtering

An early prototype visualisation is presented in Figure 4-27 with activity snap details for the “NZ Vineyards” activity. The activity snap content shown is adjusted to simulate query-based filtering of the view content. The selected activity segment once again corresponds to the entire spatial context, but is filtered based on a user query. Some changes in the design here include the use of thumbnail previews for the web sites, and action markers (used to indicate emails and location visits for example).

USAGE

Similar to developing and using a small set of personas to drive the development process (Goodwin, 2001), an assortment of activity snaps are necessary to support detailed design, prototyping and evaluation.

The selected activity snaps need to be based on a small, but varied and representative set of user activities to adequately grasp different kinds of information behaviour, work characteristics and activity evolution in a system. For example, Aran’s activity of developing his art portfolio would show characteristics, patterns of behaviour and change over time that are very different

to Mijke's activity of planning a family trip to Greece. The idea is to use these activity snaps in interface visualisations to explore and understand user work as consisting of:

- personalised activity spaces (e.g. activities that are unique due to the behavioural patterns, unique interactions and contexts, personal annotations and artifacts of users),
- evolving trails of information use (e.g. through users exploring, gathering, sharing and manipulating information over time in activities),
- knowledge work (e.g. in carrying out various related activities, with real and virtual elements like conversations and e-documents, that are used to develop ideas, build knowledge and share outcomes), and
- social navigation (e.g. by sharing viewpoints, information and information trails, and by using shared trails as a starting point for a new activity).

At the same time, the activity snaps and underlying user activities also need to be appropriate for the various visualisations designed, to get the full design and evaluation benefit of using realistic activity data. For example, Lisa's "Newsletter" activity would not help design, evaluate and refine a location-oriented map view, while her "NZ Vineyards" activity would.

Each activity snap is created using the content creation techniques described before, and subsequently applied to the corresponding visualisations, first in the interface designs and subsequently in the prototype views. An activity snap is never static, as it develops in detail, evolves and changes with deeper understanding of the user activity, the project needs, the development phase or the state of the prototype.

The selected set of activity snaps together forms the explored segment of the persona's information space. Using the persona and abstract scenario description, the rest of the persona's information space also needs to be mapped out with a few details as discussed before (i.e. to form the persona's information space snapshot). These details can include other activities for the time-period considered and their relationship with the activities that the activity snaps focus on. These supporting activities need to be described only briefly by their name, a short one-line narrative of their focus, details such as their start and end dates and so on. For example, Lisa's wine-tasting activity was never described in an activity scenario or mapped out onto an activity snap. However, this activity and other secondary

activities flesh out her information space and form a context for the activities of interest. When creating visualisations that depict a persona's entire information space, these secondary activities and information space details help create realistic detail and context at that level.

Activity snaps form a high-level design and development tool, similar to personas and scenarios. Their use assists with system development in a variety of ways, specifically as activity snaps approach real-world information-interaction and use. They essentially help developers understand, design, examine and test, evaluate and refine the system concepts, design and prototypes. Here we look at their use in more detail.

Information design (Conceptualisation and system design stages)

Early on in the design process activity snaps help with understanding user activities, specifically through the activity data itself. This data encapsulates the information objects used to carry out the activity, by explicitly quantifying and defining them, their context, their relationships, user behavioural patterns and actions. Consequently, they provide tangible and realistic material to support the design of the underlying information architecture, information communication protocols, alternative visualisations, and the visual elements for representing and interpreting the information in visualisations (Rosson and Carroll, 2001), so that they match user work and information interaction. For example, by explicitly looking at activity data as with the 'NZ Vineyards' activity, it becomes clearer what kinds of information properties and relationships need to be supported for activities and content items in the information architecture with respect to descriptive details, contextual data, relationships, annotations and so on. In this way, activity snaps shed light on the actual use of the visualisations, the system and its functionality for carrying out activity work.

Interface design (Design stage)

Once the design process starts (through brainstorming sessions, paper prototyping, considering alternative designs and the design rationale), activity snap data can be incorporated into the physical designs to drive design ideas and alternatives for presenting that information, as well as spot issues in understanding the user

activities or various design elements. Simultaneously they provide a powerful check for designing and improving the information visualisation and interaction to better support user perception, interpretation and making sense (Norman, 1988) by examining and following the activity information displayed in the designs or prototype visualisations.

From the moment activity data are worked into the physical design, ideas for refining the design (e.g. information representation and visual cues) become immediately apparent. Design elements that are hard to perceive or interpret (e.g. activity or item annotations that are not indicated in the view itself) become more obvious with the use of actual data because of the knowledge of the underlying activity and persona behaviour, than when using no data or dummy data. When the designs present real and meaningful information, interpreting and making sense of the information is automatic (e.g. activity progress or change of direction in the work) and exposes any design problems or possibilities.

Furthermore, as the content has meaning and is associated with a persona, potential use of the system in the real-world becomes more apparent, allowing the designers to detect and iron out various issues in both the underlying conceptual models and functional requirements.

Functionality and task design (Design and prototyping stages)

The use of real data in the interface designs allows developers to consider the requirements for functionality, and map these out onto options and specific actions that the persona can apply to the visualisations or the information items on the interface. For example, querying information and viewing the results according to their context, could be designed for visually (e.g. the query interface) by using the activity data to provide examples of query criteria and useful options. Using the activity data, the result set can also be simulated and presented on the interface. This allows the actual data to dictate aspects of system functionality and how the functionality should be supported by the interface for appropriate user interaction and interpretation.

Furthermore, the activity data can also signal the need for other options not yet considered. Similarly designing the supporting tasks for an activity that consist of the steps or actions to perform a task - such as adding and reviewing annotations,

swapping between activities, filtering the information space according to specific criteria and so on - becomes more intuitive with actual data to support the tasks.

Interaction design (Design and prototyping stages)

At the onset, interaction design occurs alongside the design of the system interface, functionality and tasks, with the envisioned requirements in mind. When prototypes present an activity's information objects and details in the visualisations, the visualisations start to give a further understanding of the interaction that they, the activities and the various information objects naturally lend themselves to. As a result, the activity data itself drives the interaction design, both in incorporating interaction elements anticipated through the requirements as well as adjusting and developing these to work with the type of information supported in the system. In the example of the "NZ Vineyards", the spatial map view demonstrated the usefulness of a navigable birds-eye-view, single-click swapping between map and chronological views, panning and zooming in synchronicity, the potential use of providing different information at different zoom levels and which information that could be and so on. Instead of being a static tool, the activity snap also allows developers to immediately test out interaction on realistic visualisations, review and refine the options.

Testing (Design and prototyping stages)

Once the activity data is incorporated into the prototypes, prototype functionality and interaction can be tested through initial walk-throughs and heuristic evaluation, followed by detailed test tasks using the activity information. These can show up any limitations or issues with the options provided, the action sequences in user tasks, the modes of interaction or lack of interaction options, and further design flaws.

The walk-throughs go over the prototype interface content and functionality according to the provided features and their operations, and the interaction sequences envisioned for the prototype. Accordingly, the activity content in the various visualisations is surveyed in detail and used to try out the system options and operations. The potential use of the system in the real world also becomes more evident with the realistic activity content, which can help find matches and

discrepancies between what is offered by the prototype, user needs and the system requirements.

The test tasks are more specific. They are designed for the personas and activities represented in the various activity snaps, to match persona needs and behaviour as well as the specific activity use and interaction. Test tasks focus on specific user tasks or goals, system functionality, and interaction. A number of representative tasks are selected for each persona that cover various activities and visualisations, as well as intermittently the persona's information space in entirety. These tasks then form part of a test schedule that is documented and carried out for each persona.

For the 'NZ Vineyards' activity snap, a test task might focus on Lisa's need to find several organic wines for her next wine-tasting get-together. The task might consider several prototype options, including the filter and query options, according to Lisa's preferences and behavioural patterns. The test task can take on a scenario format and include the task or goal description, the system options to explore according to the persona's inclinations, and the sequence of actions to complete the task or achieve the goal for each option tested. In completing the test task, issues the persona would have with the prototype are highlighted, thereby offering more insight into system design, functionality and interactivity than the walk-throughs alone can give.

User Evaluation (Design, prototyping and evaluation stages)

Activity snaps can be used with user evaluation in the design and prototyping stages, to provide both user-objective and user-subjective, qualitative feedback. User studies can incorporate exploratory tasks that allow the user to consider a persona and various activity scenarios before viewing and interacting with various designs and prototype visualisations that include the corresponding activity snap content.

Activity snaps can be also useful in carrying out Wizard of Oz type studies (Dahlbäck *et al.*, 1998) in the design or early prototyping stages. They populate the designs or part-functional interfaces with realistic information, and can include details that cannot yet be tracked or registered. The latter is of particular use for applications in ubiquitous computing.

Activity snap content provides greater understanding of how each participant perceives and makes sense of the information presented in the interface, than simplistic dummy data can. This largely happens as participants inherently interpret the activity data they see in relation to the persona and his/her activities, information needs and interaction, all of which mirrors real-world use of the system. Participants also reveal details of their own mental models and information behaviour, as they explain their views and preferences, and question or comment on the presented content.

Incorporating activity content moreover gives insight into how users interact with the interface functionality, manipulate information and interpret the results in line with the given activity scenario and activity snap content. For example, in swapping from a map view and a chronological view for the 'NZ Vineyards' activity, participants can relate the feature and its use directly with its potential usefulness for the activity, such as viewing the last visited wine and vineyard web-sites or the last state of the activity.

In comparison tasks, users can compare interfaces or applications by considering the same activity data. The focus shifts from mere interface elements to the real-world work that the systems support. For example, users can compare an InfoMesh map view of the 'NZ Vineyards' activity and a hierarchical folder view of the same activity documents. The richness and meaning inherent in the activity snap content, help participants to draw out the strengths and weaknesses of the visualisations as it pertains to actual user activity.

So far the use of activity snap content described for user studies is user-objective. The presented activity content is the same for all participants in the study. A second and powerful application of activity snaps in the evaluation phase is to carry out user-subjective evaluation. This is when a study or study segment is tailored to the participant and his/her own information work to get extended, individual feedback through reactions, perspectives and preferences to the designs or prototypes. For this, the study has to include one or more activity snaps based on the participant's own personal activities and activity data (i.e. the activity's information objects and contextual detail). This can be done by creating an activity snap listing for a selected, comparable activity for each participant (using method 2 or 3 discussed previously) and converting this to view content for a visualisation. When using method 2, a pre-study interview with the participant can

help in obtaining content and associated details for a recent activity (e.g. activity descriptions, goals, duration, contexts, and chronological folder listings of documents). In support of method 3, participant work can be tracked for a specific activity for a set time period. Where participants are from a similar background (e.g. students within a department, office workers at a branch), selecting a recent and common or similar activity, allows the study to showcase the individual differences in use and behaviour.

When the information presented is their own, participants can better interpret the visualisation content and features, and judge their usefulness. Participants can also comment on and question elements of the prototype design more thoroughly, as issues would be more obvious when regarding their own activity work. Consequently, this kind of study tasks provides feedback that is user-subjective and in-depth, highlighting individual preferences, user information behaviour and the scope of personalising the interaction experience.

By incorporating participant-based activity data that approaches real-world use information, the user-subjective study tasks further create a stepping-stone between short-term lab studies and long-term real-world studies. Care is required however in analysing these findings, specifically as they are qualitative and subjective.

Findings from both the user-objective and subjective studies give detailed insight into how users perceive, interpret and make sense of the rich, meaningful information as it is presented by and manipulated through the designs and prototypes. Hence, these findings help discern and refine issues discovered in the underlying models and metaphors, interface and interaction, functionality, general usability and other areas.

System Deployment (Deployment stage)

Activity snaps are a valuable tool in preparing user manuals and video tutorials to help users understand the system ideas, interface, features and functionality, as well as its everyday use. Users can be presented with a description of the system goals, a persona and activity scenarios, followed by a walk-through of the system using screenshots with corresponding activity snap content and matching explanations. This organisation exposes system use naturally through a story-like

format that moves from character (persona), background (scenario), narrative (activity scenario) and visual content (activity snap in screenshots).

Where a system tackles information-interaction that can vary according to user preferences and natural intelligences (such as symbol, person or object related), illustrating this variety through diverse personas and activities can help users see how the system can match their own unique needs. In this situation, the same visualisations can be presented for different types of activity work and information-interaction, which can further also reveal the different ways the system can be used.

Activity snaps extend the use of personas and activity scenarios to form realistic examples of use and are also helpful as sample content in a deployed system for user exploration and learning.

BENEFITS AND USES

The benefits activity snaps offer the development process focus chiefly on three things, as explored previously:

- clarifying and illustrating user activities, their characteristics, content and evolution,
- augmenting existing tools for conceptualising ideas, designing a system, divining the use and appropriateness of the design, and the usefulness of the system, and
- supporting the testing and evaluation process with realistic data, for functional tests, analytical evaluation as well as user-based objective and subjective studies.

Activity snaps, like personas and scenarios, are of ultimate use in the design of novel or complex interactive systems. They especially come to the fore in the development of interaction- and information-rich applications that are personalised to the user, as well as cross-device applications for the ubiquitous / pervasive computing environment.

Interaction- and information-rich systems that are personalised to users require an in-depth awareness of user information behaviour and actions, and information and context objects that characterise evolving user activities. Activity snaps combined with personas and activity scenarios greatly assist with this, especially

where information and interaction are highly visual, as experienced in their use with developing Pervasive Personal Information Spaces.

Another advantage of using activity snaps was also discovered through their use in this research. They allow the process of discovering and refining usability issues to start much earlier, as various issues in design and functionality become immediately apparent with their integration into early designs and prototypes. When user studies come into play, study findings would be more useful as the activity snaps would have already helped in ironing out some of the early issues. As such, they have the potential to be time and cost effective in the development of novel and complex interactive systems.

Finally, in the development of cross-device systems, activity snaps help developers adapt prototype designs, examine and evaluate the prototypes developed for each system, and compare them by interacting with them through the same activity content. For example, in user studies with InfoMesh, participants were presented with PDA and desktop InfoMesh versions with the same activity snaps and underlying scenarios. This allowed them to readily comprehend, interact with and compare the interfaces and comment on their use, by focusing on the activities and activity content rather than simply the interface alone.

In existing research and system development, developers apply data sets for various purposes, ranging in use from test data to sample content. However they differ from activity snaps in numerous ways. These sets of data can for example often be:

- Dummy data with limited meaning, as they are not tied directly to a user or persona, and their activities,
- Data that does not support rich associative or contextual details, and so cannot show the evolution of user activity and information-interaction, information behaviour patterns, work context and realistic trails of information use,
- Limited in variety and number, so that they give only one or simple perspectives on information use,
- Incorporated late into the development process as raw data sets to test-run an application for accuracy or as an example data set for populating the final prototype to illustrate its use, and

- Stand-alone, as opposed to acting as a streamlined tool for generating ideas, driving design or aiding evaluation throughout the development process, alongside existing tools.

Activity snaps carry realistic meaning due to their close association with personas and scenarios, and their rich detail when converted to visual content. By further employing them throughout the development process with representative variety, they form a multi-faceted development tool.

Theoretically, the visual activity snap can be described through a user interaction scenario. This scenario would in all likelihood be a long narrative of user interaction and thought processes, with perhaps supporting diagrams. However the narrative would not be able to showcase the dynamic, visual identities, and context and relationships of high-level user activity and information objects. Activity snaps directly populate designs and visualisations, aiding design and design refinement in a way that a descriptive scenario can not. Consequently, they help understand the complex ‘appearance and behaviour’ of information objects, not just data and controls as scenarios may (Go and Carroll, 2004).

Through their use and the experience gained in this research, activity snaps show much promise in extending the use of various design tools to drive and illuminate the numerous stages in system development. There is currently no similar worked-out design tool for exemplifying a system’s underlying information items according to representative users and real-world use, to help with information design as well as the design of information presentation and interaction. Activity snaps fill this gap in informing design and development, and may practically benefit both research into novel information interfaces and commercial system development.

4.3.3 THE PSA-BASED DESIGN AND DEVELOPMENT PROCESS

The research into Pervasive Personal Information Spaces has shown that personas, scenarios and activity snaps work well in combination to support system development from conceptualisation to deployment. All three tools offer high-level design and development support, with artifacts that evolve and are refined through the development cycle to match the requirements at each stage. Together, they further support both progressive design and pervasive usability.

Personas, scenarios and activity snaps (PSA) based design and development can be advantageously employed in an iterative and evolutionary development methodology, and more specifically as a foundation for user experience design. Table 4-1 presents PSA development and use through the various phases in the system development life cycle, summarising when artifacts are created and how they are utilised. The artifacts and outcomes of each phase inform each other phase.

The table listing acts as a simple set of steps or guidelines for incorporating the PSA methodology in system development. (Detailed usage is covered in previous sections and through the various examples presented in this thesis.)

PSA Life Cycle	
Phase	Development and use
1) Conceptualisation	<ul style="list-style-type: none"> - Several personas with information-interaction details, informed by interviews and field studies. - High-level, exploratory scenarios summarising selected personas' activity work. - Example activity scenario to explore the current, envisioned and future computing situations, so as to understand issues in the existing environment, new and feasible interaction solutions for direct implementation, and ideal future solutions. - Select activity scenarios for each high-level scenario for the chosen persona(s). - An information space snapshot for the selected persona(s), i.e. a sketched out information space with details of the main activities of interest and secondary activities. - Snapshots of each chosen activity's context over time. - All of these design artifacts are used to kick-start the conceptualisation and design brainstorming processes. - The artifacts serve as discussion objects as well between designers, developers, users and stakeholders. They can also be presented to users to verify understanding of the activities, their content and information-interaction behaviour.
2) Design	<ul style="list-style-type: none"> - Activity snap listing of information and context objects for

	<p>each activity of interest.</p> <ul style="list-style-type: none"> - Activity snap listings converted to visual content, by identifying representational elements. - Activity snaps incorporated in interface designs and used to drive information, interface, functionality, interaction and system design, and rationalise design choices.
3) Prototyping	<ul style="list-style-type: none"> - Activity snaps detailed further for use in prototypes. - Activity snaps generated as content for prototype visualisations using activity snap generation scripts. - Activity snaps in the prototype visualisations used to support further design as well as design refinement.
4) Testing	<ul style="list-style-type: none"> - Activity snaps used as simulated real-world content for walk-throughs and heuristic evaluation of prototypes. - Diverse and representative test tasks (task scenarios) devised for the personas, their activities and the activity snaps employed in the prototype visualisations. - Test task schedules carried out using the activity content presented in the prototype, to test prototype functionality and interaction.
5) Evaluation	<ul style="list-style-type: none"> - Activity snaps presented as part of paper designs for early user evaluation of design and underlying concepts. - Activity snaps incorporated in the prototype and used for assorted exploratory and comparison tasks in user-objective evaluation. - Activity snaps developed for each participant based on their own real-world data for user-subjective system evaluation.
6) Deployment	<ul style="list-style-type: none"> - Activity snaps used as sample content to support system exploration by end-users, and as diverse and realistic examples in user guides and tutorials to aid understanding.

Table 4-1: PSA development and use through various development phases

The PSA life cycle emphasises the use of activity snaps as the most tangible tool for incorporating personas, user work as described by the scenarios and the actual

work content into designs and prototypes, for driving and refining design, as well as testing and evaluating a system.

4.4 SUMMARY

The goal of this research is to develop and evaluate an information visualisation and interaction framework for distributed information spaces that focuses on flexible, context-based views. In implementing the framework as a system, namely InfoMesh, the design scope was limited to the functional and non-functional requirements given in sections 3.4 and 3.5.

The requirements formed a guide for the conceptual design for InfoMesh, which was explored in this chapter through desktop and PDA interface and interaction designs. These designs considered ways of envisioning context-based flexible views for personal information spaces, with versatile tools and rich, associative, annotated detail. Together these designs essentially form a design space exploration that covers a wide terrain of design elements and options for understanding and visualising context-based flexible views. As such they are useful both in investigating Pervasive Personal Information Spaces and developing InfoMesh, as well as in serving as an example for creating personalised flexible views of information and incorporating user work contexts in information visualisations.

Pervasive Personal Information Spaces in the real world are complex and span a wide area of interaction, and so the requirements could not always be directly translated into a design. A variety of design tools and methodologies helped translate and transform these requirements into the conceptual and physical design for InfoMesh, and the resulting prototype implementations. More importantly, they helped design the user experience for InfoMesh. Of note here are personas, scenarios and activity snaps, which respectively bring representative user goals and behaviour, user activities and information interaction, and realistic user activity and context data into the development process. Activity snaps are a product of this research, emerging from the need to design for real-world, user-specific activity work that is characterised by data that is richly associative and has changing context. They form a promising tool for use in designing, developing and evaluating information-rich interactive systems in the ubiquitous

computing environment. Activity snaps contribute by extending persona and scenario based design, by combining specific user and activity details with information usage and context data that can be incorporated into interface designs and prototypes.

The next chapter presents the resulting InfoMesh system, exploring its use through the persona Aran and his activities. The chapter subsequently describes the physical design and implementation details underlying the InfoMesh desktop and PDA prototypes.

CHAPTER 5 - IMPLEMENTATION

THE INFOMESH SYSTEM

5.1 INTRODUCTION

This chapter reports on the InfoMesh prototype system. The chapter first presents a walkthrough of the system, discussing InfoMesh interaction and interpretation from the user perspective. The walkthrough looks in detail at various FlexViews and the supporting FlexTools for desktops/laptops and PDAs, exploring and describing InfoMesh by utilising scenarios and activity snaps for the persona ‘Aran’. InfoMesh as a prototype system fulfils the role as an example implementation for illustrating, exploring and evaluating aspects of Pervasive Personal Information Spaces. As such, InfoMesh contributes to the understanding of how context-based flexible views can possibly provide a more natural and personalised access to distributed personal information in the ubiquitous computing environment.

The chapter’s later sections then look under the hood of InfoMesh and describe the system architecture and application components, the system environment, and the system development process. The underlying system elements show something of the numerous functional elements that have to be integrated to provide a rich visual, personalised and seamless interaction experience when developing Pervasive Personal Information Spaces. The Composer-Worker-Presenter architecture is of interest here in that it can flexibly accommodate different Pervasive Information Space implementations.

5.2 INFOMESH: VIEWING AND INTERACTING WITH THE DISTRIBUTED INFORMATION SPACE

InfoMesh is a multi-device prototype system that illustrates key aspects of the Spaces model, to serve as an example implementation of Pervasive Personal Information Spaces. The system has modified versions that run on desktops, laptops and PDAs.

Essentially, InfoMesh provides a way of viewing, accessing and managing a collection of electronic documents on a user’s different personal devices. The system makes use of user activities and user contexts (such as people, locations and devices) to relate and present views on the user’s integrated information space.

The system can be used alongside file access and management tools, such as hierarchical folder systems and desktop shortcuts, allowing users to benefit from the strengths and advantages offered by InfoMesh as well as these traditional methods. From the user's vantage point, InfoMesh is an integrated tool presenting multiple views and view options. Consequently, one way to become familiar with the system is to look at how users can start using InfoMesh, how they can use and interact with various FlexViews, and how they can manipulate their views using FlexTools. Let's do this by looking at the persona Aran, his activities and use of InfoMesh. (Several short video demos are provided online at <http://www.cs.waikato.ac.nz/~ak14/infomesh.html>, which show key views and interactions in InfoMesh as they are explored through Aran's scenarios in the following walk-through.)

Persona "Aran"

Aran is a recent graduate of Fine Arts, eager to launch himself online and off-line with his visual art. He uses several computing devices in his everyday life. His desktop at home is his central work machine, for browsing, gathering information and writing. His tablet PC moves with him as his chief drawing companion and a substitute for his desktop, in his home studio, local artists' studio and on his longer travels. Finally he carries a smartphone with him everywhere he goes, for phone calls, taking impromptu photos of interest, and jotting down notes, ideas and anything of interest he encounters.

Aran has been using computers steadily over the course of his degree, to create artwork, manage his portfolio, keep up with correspondence, maintain an artist blog, do work on commission and much more. His goal in working with his devices is to freely create and share his art, uncover opportunities, keep track of his ideas and work (including his art portfolio and writing activities), as well as pull together all his notes, art exploration and inspiration. He would like to view the development of his ideas and creative output, and follow the pieces of information (such as web pages, locations, artists and artwork, music or films) that led to the discovery or development of an idea, theme, technique or actual pieces of art.

Aran has been using InfoMesh now for a few months on his desktop, tablet PC and smartphone. He's started to use InfoMesh to support several of his creative and collaborative activities, creating matching activity views for them. He uses the views to see the direction his work takes over time, discover ideas and opportunities, and share and discuss his ideas and work trails.

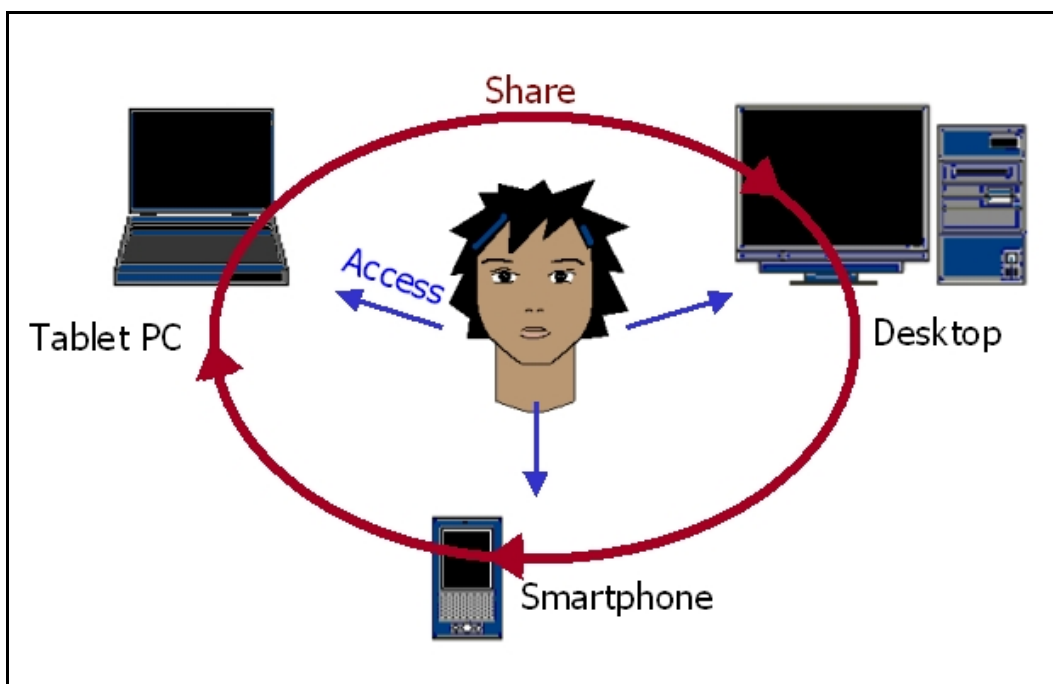


Figure 5-1: Aran's devices

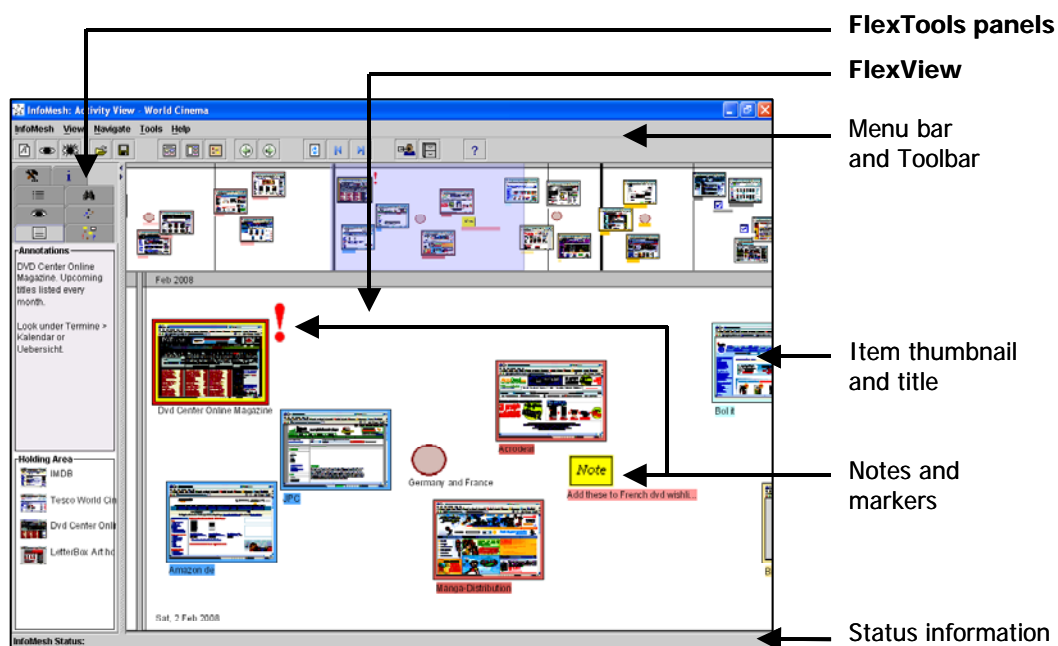


Figure 5-2: InfoMesh desktop/laptop interface components

Aran is using InfoMesh on his different devices (Figure 5-1), where the application runs in the background when he works and tracks all the documents he uses and web pages he visits. These information items are automatically added to the activities he’s working on at the time. The system integrates the documents used across various sessions and devices to present them through a variety of

views (FlexViews), according to the device he's using and his work context. He can alter and filter these context-oriented views using a varied set of tools (FlexTools).

Figure 5-2 illustrates the major components in the InfoMesh desktop or laptop interface, including several view items. View workspaces can namely contain item thumbnails and titles, view pockets, notes and markers, time information and more. Information items, notes and markers can further be annotated, colour-coded and grouped together.

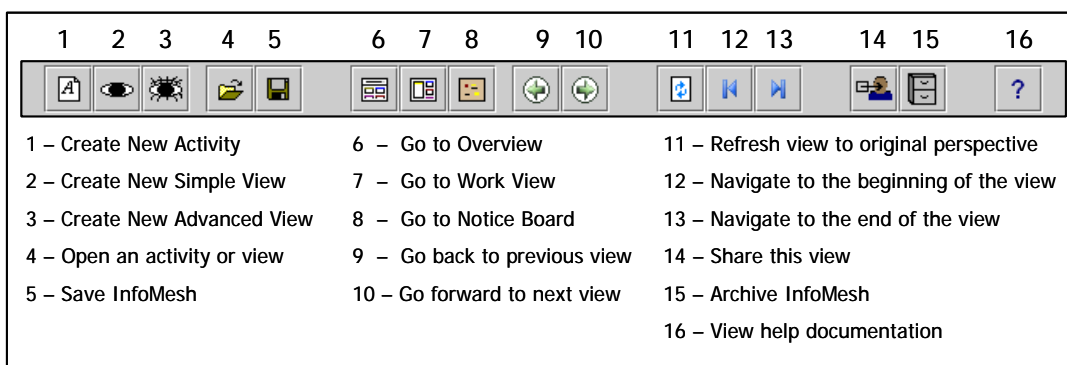


Figure 5-3: InfoMesh toolbar options

Aran can navigate through the views using a pan and zoom functionality (by dragging the view with the left or right mouse buttons), or use the navigation buttons on the toolbar (see Figure 5-3 for a listing of the various toolbar options). He can bring up an item's details in the FlexTools panels by pointing to the item, move the item by dragging it across the view workspace, or open the item with a single left mouse click. A right-click on items or the workspace brings up a context menu, with further item, marker and workspace options.

InfoMesh provides Aran with overviews of his information space, as well as activity-specific views. *Simple views* in InfoMesh only take into account a single activity (e.g. a project or hobby) and a single context at a time (e.g. time, location or people). They can however be altered in a variety of ways to match the current work context. Aran can use *advanced views* on the other hand to view documents from multiple activities, diverse collaborative groups and devices.

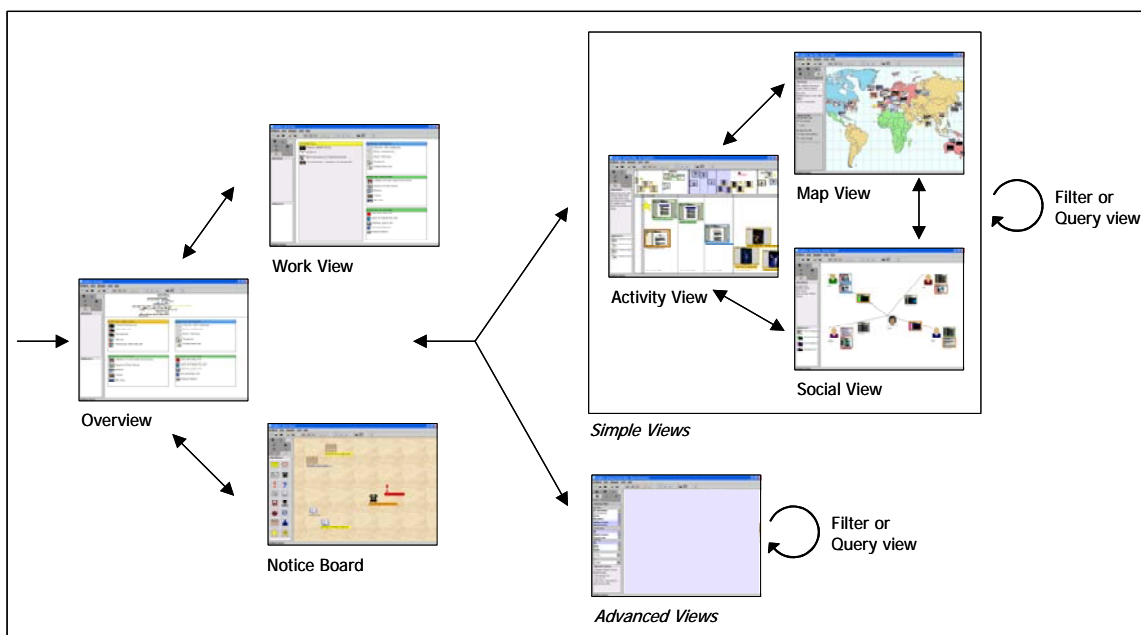


Figure 5-4: InfoMesh view navigation

Figure 5-4 depicts the different InfoMesh views and the navigation between them. We'll look at these views and their use for several of Aran's activities in the coming sections.

5.2.1 AN OVERVIEW OF THE INFORMATION SPACE



Figure 5-5: Logging in to InfoMesh



Figure 5-6: Indicating default device

Aran starts up InfoMesh on his devices by logging in (Figure 5-5). His name and password help keep his personalised views on his information space private. The first device that InfoMesh is installed on is set up as Aran's default device to house his information repository (Figure 5-6). Whenever he installs and starts up InfoMesh on an additional device, the new device is registered as a secondary device. Once Aran indicates his default device, the new device is added to his InfoMesh network of devices.

Whenever Aran starts InfoMesh on one of these secondary devices, the application updates the device with details from his central information repository. Similarly, when he finishes an InfoMesh session on that device, all the changes are uploaded to the repository and saved. Consequently, when Aran uses his desktop, tablet PC and smartphone, he has access to all of his up-to-date views on his integrated information space. He has easy access to the underlying information items as well, except on his smartphone, where various restrictions apply.

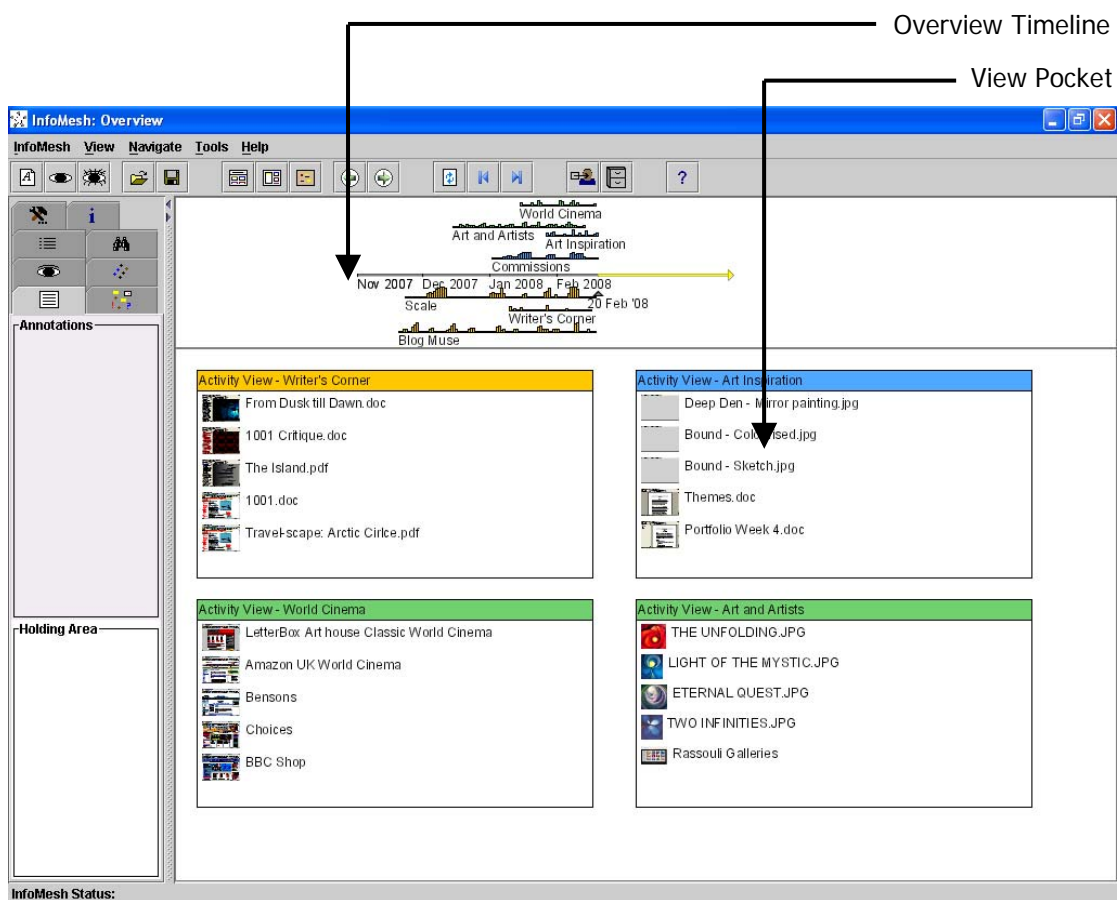


Figure 5-7: InfoMesh Overview

Usually when Aran starts up InfoMesh on his desktop, tablet PC or his smartphone, he looks at the **Overview** of the information space first (Figure 5-7). The view summarises his work state, by providing view pockets for his most recent activities and a snapshot of his information space through a timeline of activities. Most importantly, this view as with the other InfoMesh views is personalised to Aran by exposing his information space through the lens of his own activities, work context, interaction, annotations, growth and change.

Overview View Pockets: The view pockets allow Aran to see and access the activities he's working on currently, regardless of the devices he uses for the different activities. The overview in the previous figure displays view pockets for the last four activities Aran carried out or viewed, namely "Art Inspiration" (carried out largely on the tablet PC), "World Cinema", "Writer's Corner" (both largely carried out on the desktop), and "Art and Artists" (which he briefly revisited). Each view pocket (colour-coded according to activity) lists the information items that Aran last accessed for the activity. His "Art Inspiration" view pocket, for instance, shows him that he tinkered with his experimental art pieces 'Bound' and 'Deep Den' during the last session. Aran can open any of the recent activities by clicking on the view pocket title bar, or open one of the documents and implicitly open the corresponding activity's view.

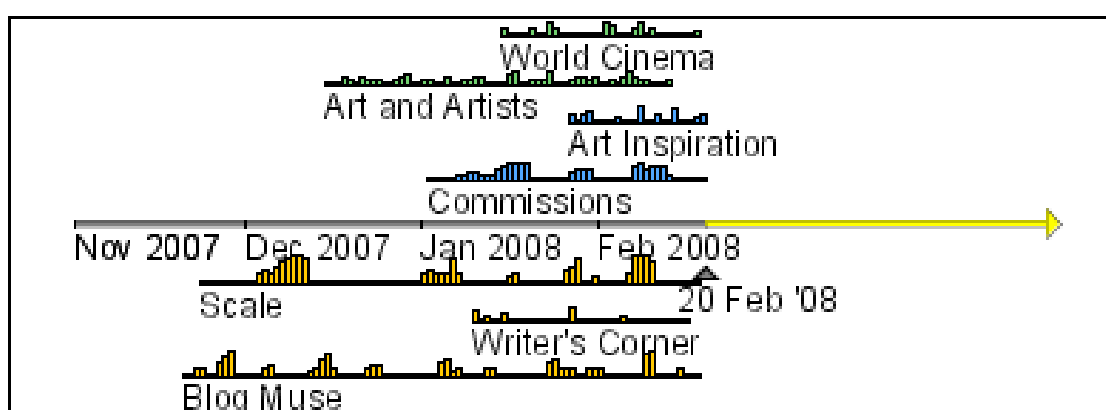


Figure 5-8: Overview timeline close-up

Overview Timeline: The overview timeline on the other hand depicts all his activities, their progress and relationships, allowing Aran to see what he's been working on over time and where he's headed. On his timeline (a close-up is presented in Figure 5-8), Aran has arranged the various activities around the

timeline by moving them up or down (for example, he's arranged all his writing activities below the timeline). The activity histograms support vertical movement for arranging activities according to user preferences to help make comparisons, or to denote any relationships or priorities. By keeping "Art Inspiration" and "Art and Artists" near one another for instance, Aran can see how an intense period of looking up various art may perhaps have inspired and spurred on his own portfolio work in his 'Art Inspiration' activity.

Aran has further colour-coded the activities to signify their relationships. He's colour-coded his writing activities orange ("Blog Muse", "Scale" and "Writer's Corner"), his creative work blue ("Commissions" and "Art Inspiration"), and his other interests green ("Art and Artists" and "World Cinema"). All representations of these activities (e.g. on the timeline or as view pockets) carry this colour-coding to easily indicate activity and/or area of interest.

The overview timeline supports a past-present-future arrangement that goes from left to right, with a current granularity that shows month-based delineations. An arrow denotes the current day of access (20 February 2008 here, indicating the time Aran opened InfoMesh). Aran can travel through time by panning the timeline workspace horizontally, and zoom in on any activities he's interested in. He can also pan vertically or zoom out to see more of the timeline. The yellow part of the timeline alludes to the future, and Aran can potentially place notes or other information items for the future in his activities that will be displayed here to serve as reminders.

Each activity on the timeline is represented by a histogram. The length of a histogram indicates the duration of each activity, while the changing height shows the interaction frequency or intensity of work carried out for an activity. For example, Aran started using InfoMesh mid-November, and started work on his portfolio through the "Art Inspiration" activity late in January of 2008. He intermittently does work for "Writer's Corner".

Aran can use the histogram depiction to track work progress (e.g. he notices that he hasn't looked at new art by fellow artists in the past week), find periods of intensity or lulls in an activity (e.g. to check whether he's been working steadily on his portfolio), and be aware of patterns in his work (e.g. he usually writes for the Scale e-zine the first week of every month). Aran can go to an activity's view at a specific instance in time by clicking on the activity histograms, and view the

activity's information trail and access all the underlying information items, regardless of whether he's at his desktop or tablet PC. Though Aran can look at the various views, his smartphone currently restricts access to items.

Over the long run, the timeline also allows Aran to infer which activities were carried out concurrently and any work patterns that emerge around that time. This allows him to see how one activity may have influenced another (e.g. the films he watched as part of his interest in world cinema may inspire specific ideas or themes as he tracks his artwork and art inspiration activity).

As InfoMesh tracks Aran's work over months and years, the overview timeline can allow him to interpret his entire evolving information space, his work and activity behaviour. The timeline would show the evolution of his interests through the changing direction of his work. The chronological progression of old and new activities then helps him track his accomplishments and various milestones, and chart his future goals. For example, his degree courses and graduation in 2007 would make way for his professional and creative activities as an artist in 2008. In this way, his information space visualisation records his *lifelong learning*, growth and change.

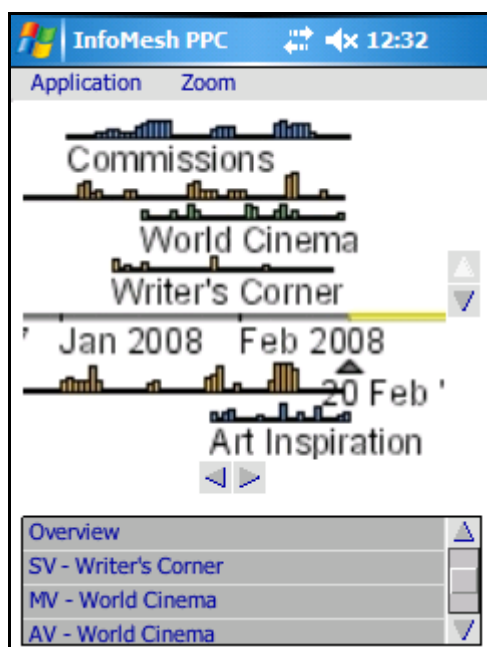


Figure 5-9: InfoMesh Overview on PDA

PDA Overview: Figure 5-9 shows the overview visualisation on a PDA, which leaves out the FlexTools panels to instead support some basic options through the menu bar (such as switching back to the overview or viewing at different zoom

levels). The view mirrors Aran's desktop view in a simple fashion to give him access to the overview timeline and recently accessed views when he's using his smartphone. He can scroll across the view using a stylus to glance over his work. Aran finds the overview useful on his smartphone when on the go or meeting with friends, to quickly check up on his activities, view his progress, decide whether he can take on some other work, and so on.

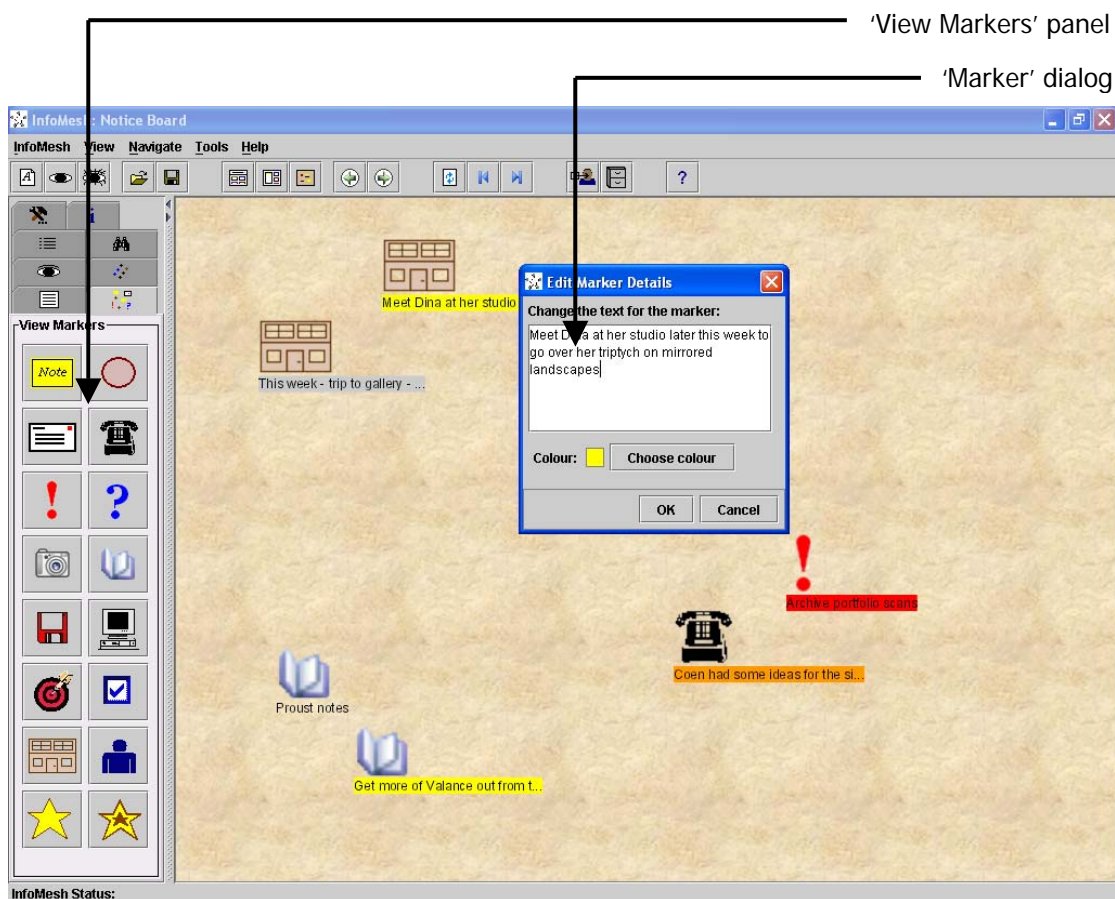


Figure 5-10: Notice Board

Notice Board: At the end of a session of work, Aran usually checks the **Notice Board** (Figure 5-10) before signing out of InfoMesh. This view mirrors the use of a simple notice board for adding general notes and reminders. Aran often uses the notice board view to quickly add notes, to-do lists, events and markers to remind himself of anything that he suddenly thinks of or still needs to take care of. For example, here he has some reminders for making a trip to a local gallery, meeting up with Dina and calling up Coen about a web-site (the notes are displayed in full in the 'Annotations' panel when Aran hovers over the item).

Clustering items, colour-coding and the use of various action markers and symbols also help categorise and prioritise items on the notice board. The red colour-coding and exclamation mark for example are meant to grab Aran's attention to archive scans of artwork in his portfolio the next time he uses InfoMesh and looks at the notice board. The previous figure shows the 'View Markers' panel open on FlexTools that Aran uses for adding markers to the view, as well as the dialog for editing marker content.

Aran also checks his notice board on his smartphone from time to time when he's on to go, adding ideas and notes for the view when he's meeting with friends or visiting places. Currently the notice board view, as with other InfoMesh views on the PDA, supports viewing, panning and zooming. The PDA version of InfoMesh however does not support interactions for downloading, opening or adding items to the views, due to limited implementation. Aran can however create notes, write or sketch out ideas on his smartphone, that InfoMesh will track, relate and add to his information space and views on his next desktop synchronisation.

5.2.2 ACTIVITY VIEW: 'ART INSPIRATION'

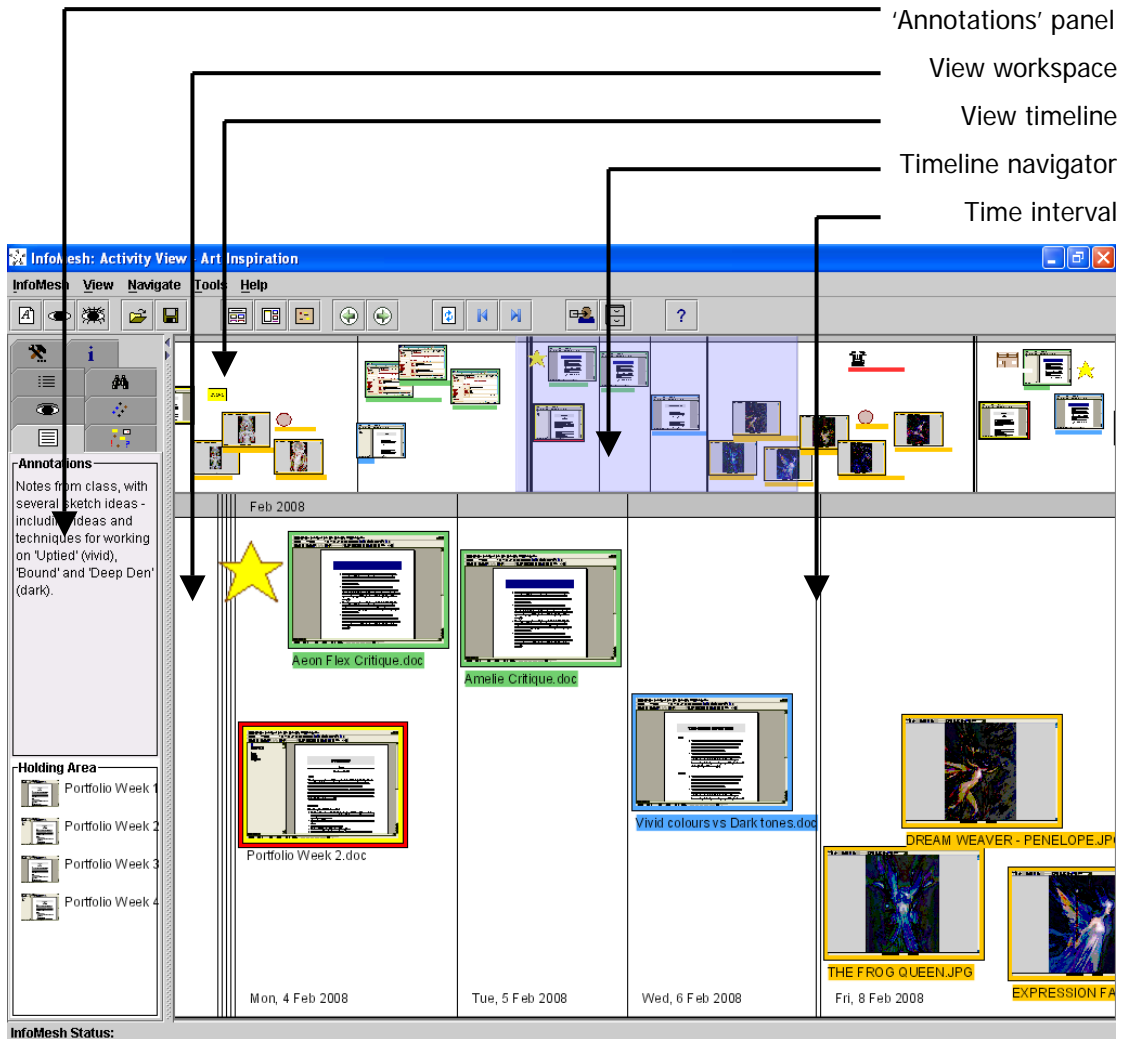


Figure 5-11: Activity View for Aran's "Art Inspiration" activity

Activity scenario for "Art Inspiration" activity

Aran is working on a new portfolio of work, around a central set of themes. He's been looking at artwork, reading snippets of literature, watching movies, and visiting places, to find inspiration for his themes, motifs and ideas. At the same time, he's been turning out different painting and graphic design pieces, linking them in his Art Inspiration activity with his own annotations and the things he's looked at to get inspiration. Over several weeks, he's slowly developed his ideas and themes for two sets of artwork, which he's starting to paint digitally and pull together. He's given himself a deadline of a month to develop the foundation for the portfolio, before moving to the next stage. He's also been in contact with a small, local art gallery for showcasing his work in several months time.

Aran does most of his reading and browsing for his activity on his desktop (and

occasionally on his smartphone) and his artwork on his tablet PC. Every month he archives his main activities, including 'Art Inspiration'. With InfoMesh, he will have all the intricate, annotated views along with the information items to help him understand his progress and to build on any other ideas that he meant to pursue at a different time.

Aran uses the InfoMesh **Activity View** (Figure 5-11) to track the work he regularly carries out on his desktop and tablet PC. This view presents the information objects used as part of an activity on a chronological workspace. The timeline in this view is an overview of the workspace, supporting navigation and interpretation of ongoing activity. The workspace lists documents with thumbnail and title information according to their time of use, and supports a variety of item and workspace annotations.

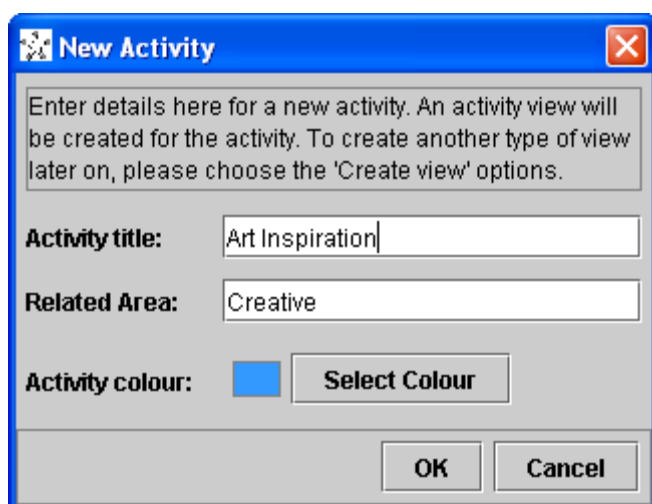


Figure 5-12: New Activity application dialog

When Aran first creates the activity, he uses the 'new activity' option on the toolbar and enters the activity details in the dialog that opens up (Figure 5-12). At all other times, he uses the 'open an activity or view' option on the toolbar, to select and open "Art Inspiration" as an activity view from a dialog that lists all his activities and views. He does most of his digital sketching and painting on his tablet PC, adding photos or scans of any physical art pieces he makes to the "Art Inspiration" activity. This way he tracks all his work on his portfolio chronologically through the activity workspace. Aran uses the view to see the development of his work through phases and ideas, and to infer the changes in the direction and actualisation of his work.

Activity View Workspace: The current screenshot of Aran's activity view workspace shows various artwork and writings he's looked at, on a particular set of days, to inspire him and help him conceive a theme for his work. When Aran first opens an activity view, he is immediately taken to the right most part of the workspace (corresponding to the current time) reminding him of his most recent work.

The activity view workspace progresses chronologically from left to right. InfoMesh tracks Aran's information usage behind the scenes, as he creates, modifies and accesses information items for his activity (through, for example, the InfoMesh visualisations, a web browser, the folder system or the desktop). Documents and bookmarks that Aran creates, modifies, deletes or renames, and web-sites he accesses are automatically registered and updated to the activity view. As they are inserted into the view workspace, item associations begin to form based on their use together over time, forming an information trail of Aran's activity work. (Items are inserted automatically with a vertical arrangement that matches file type, which Aran can re-arrange as he chooses to). Aran can pan and zoom on this workspace, use the navigation buttons on the toolbar to move to the beginning or end of the workspace, or use the refresh button to bring him back to his current work state.

Activity View Timeline: The view's timeline provides a context for the information presented on Aran's workspace, and is simply a smaller version of the chronological workspace. The timeline shows the changing emphasis in the activity through the visual cues offered by the workspace items and notes, colour-coding and item arrangement. Aran can use the timeline to get a chronological overview or big picture of the activity workspace. He can move the timeline navigator across the timeline to swiftly scan different parts of the activity and navigate to a particular segment of the workspace. Aran can also zoom in or out on the timeline to view items.

View Content: Aran's activity view contains many information objects, besides the thumbnails and titles of the documents and web pages he accesses. These include time information, item colour-coding and arrangement, and various markers and annotations.

The workspace indicates the time of interaction through date information and intervals. The lines with date information separate days of work (e.g. Mon, 4 Feb, 2008 when he went into his second week of working on the portfolio idea development). They also show work continuity by indicating intervals when no work was carried out (e.g. Aran took a few days off before February 4th when he went away on holiday for a few days). The date intervals can be lines of various thickness and colour to indicate the length of the period of inactivity (e.g. intervals of weeks and months are thicker and darker than intervals of days), so that a quick glance allows interpretation of when Aran worked or took time off.

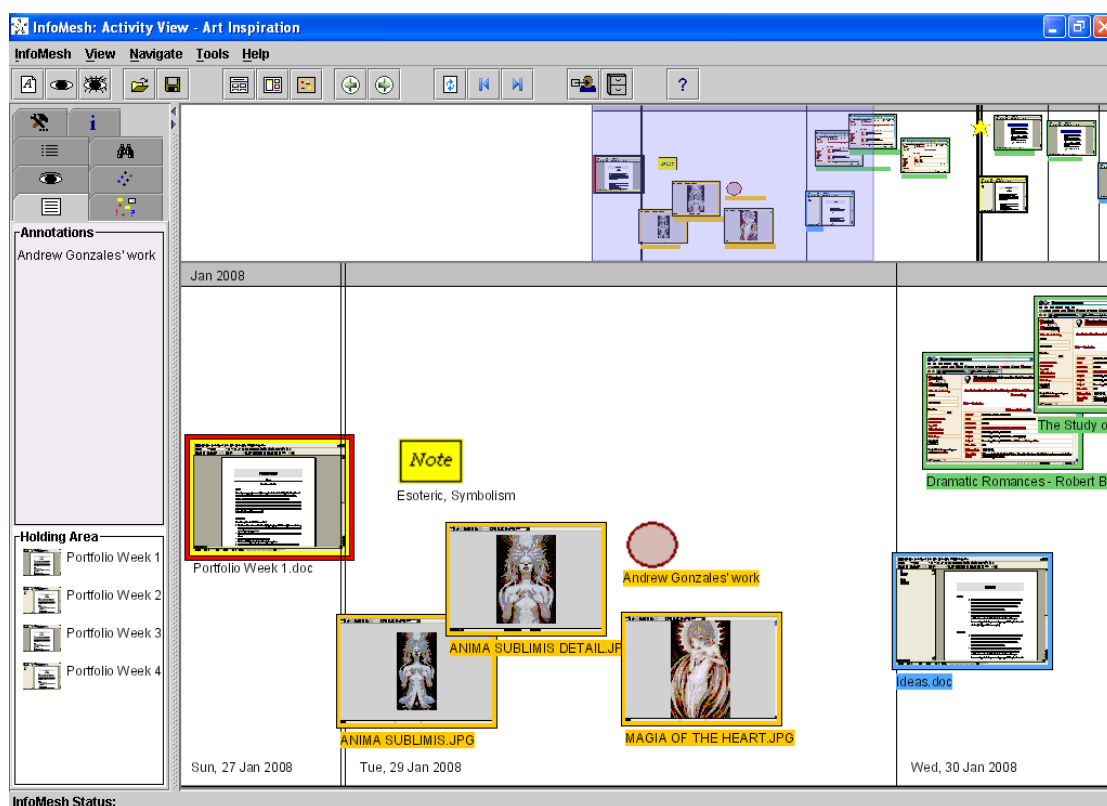


Figure 5-13: Retrieving information using the 'shape' of an activity over time

Aran can annotate view items in a variety of ways. He has for example colour-coded various information items. In this activity he's coloured artwork he's looked at orange, writings he's read green, and his own ideas and work blue. At a glance, Aran can make out from the view timeline and workspace, the types of material he has considered or created for the activity. Grouping items on the workspace allows him to relate documents, images and ideas more closely, giving shape to the information trail. (Aran can move items on the workspace, but within limits so that the timeline still remains meaningful.) This colourful shape of the

activity supports further personalised information retrieval. Aran for example remembers that he looked at a particular work by Gonzales that sparked a new idea for a design technique. As he does not seem to have the idea noted in his ideas document, he just looks through the timeline to retrieve the orange arrangement early on in the activity that he recognises as his review of Gonzales' artwork to revisit the items and recall the idea (see Figure 5-13).

The activity view allows Aran to further annotate the view with action markers and symbols, as well as notes for individual items. Aran has for example added a keyword anchor to Gonzales' artwork indicating the artist name, as well as a workspace note that he now uses to recall the idea he had for the design technique. In the 'Annotations' panel, Aran can further see the notes he's added to specific information items, workspace notes, markers or symbols in detail. At any time, Aran can query the view using FlexTools across the content of these markers and notes. The 'Annotations' panel also lists documents that Aran has flagged as important in a holding area for quick access (the previous figure shows that Aran has flagged all his weekly portfolio development plans as important).

All of these various annotations to the view (including colour-coding, grouping, markers, symbols and notes) create a unique activity landscape, which supports a personalised *navigation of the information space*. Information retrieval can then be both 1) explicit, through direct queries and filters on the information space, and 2) implicit, through changes over time, the rich information associations, and a distinct and colourful activity landscape, all of which offer a variety of contextual retrieval cues. This changing activity landscape, both on the workspace and timeline, allows Aran to recognise his work content, the sequence of his work, periods of activity and inactivity, and the evolution of his activity or changing direction of work.

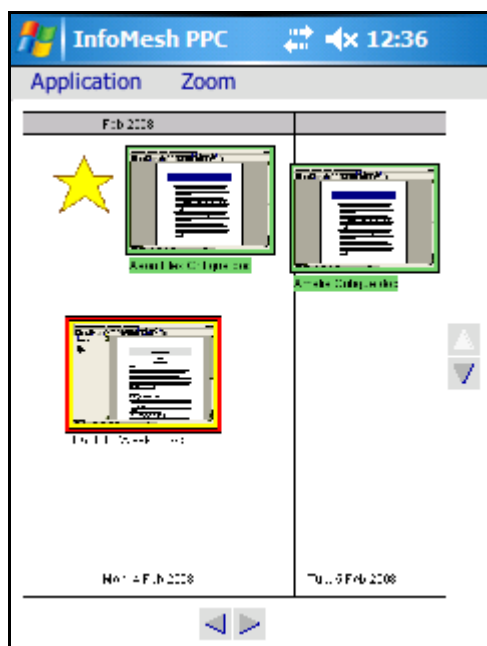


Figure 5-14: InfoMesh Activity View on PDA

Task scenario for incidental use of smartphone for “Art Inspiration”

Aran looked at the writings by Browning and Lawrence on his smartphone while he was waiting at a café to meet a friend. He was looking over his “Art Inspiration” activity to think of places to visit or things to read to develop some ideas. The café had a wifi-hotspot, and on a whim, he downloaded a few writings from the Gutenberg website for perusal. Once back home, these items were uploaded to his information repository on the desktop and associated with the “Art Inspiration” activity when he synchronised his smartphone.

Tracking and Integrating Information: Every one of Aran’s activities has an associated activity view that is automatically tracked for him. InfoMesh updates these views continually even when other context views such as social and map views are created and used for the activity as well.

The chronological activity views bring together the work Aran carries out on any and all his devices, associating them together within the context of the same activity (see Figure 5-14 for the PDA version of the activity view for ‘Art Inspiration’ using 50% zoom on the view). InfoMesh tracks various contexts in part automatically and in part through user specification. For activity views, these include details about the activity, the information items used and their source, time of use and time-based information associations, devices of use, and

document authors and the people items are shared with or by. Consequently, these views show Aran's current and previous state of work, work development, changing use context, and trail of information use in an annotated, associative and visual way, which personalises Aran's interaction experience to his activities and work context. Interaction moves beyond the level of individual devices and tasks and files, to a higher level of activity support within a rich, integrated information space.

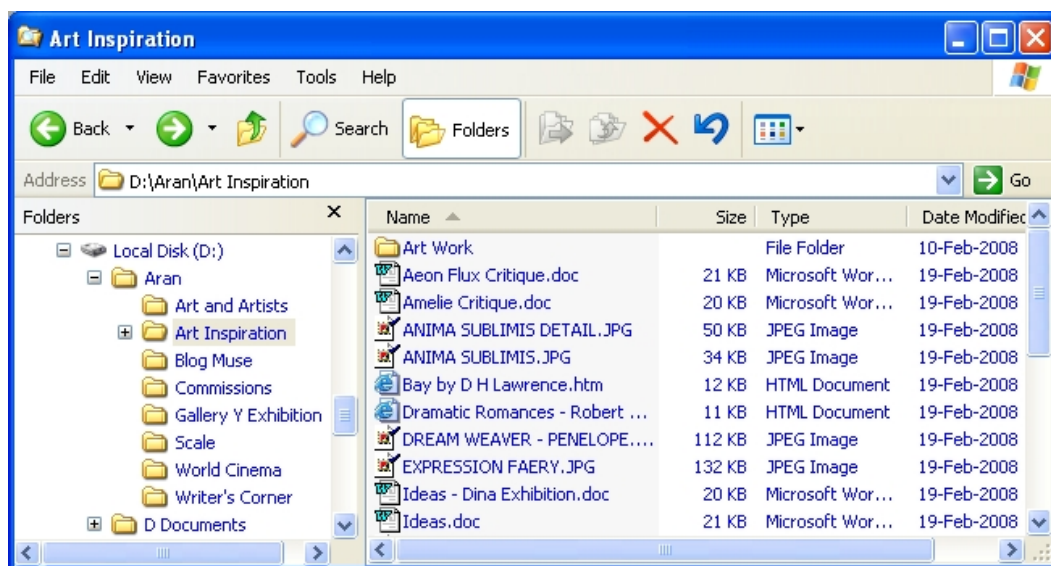


Figure 5-15: Hierarchical folder view of Aran's "Art Inspiration" files

All these details, interpretation and personalised experience are difficult if not impossible to garner from hierarchical folder views of the underlying information items (see Figure 5-15 for a view of Aran's 'Art Inspiration' files), though the folder views have other strengths. One clear example is that the activity view creates multiple references to the same item according to its use over time. Each reference has associations with other items at the time of use, and indicates something of the work carried out at that specific time. Aran writes up ideas in his 'Ideas' document on different days for instance. Each time he accesses the file, the reference on the activity view shows the other items that he looked at around that time for inspiration or techniques. The folder view lists 'Ideas.doc' only once with the latest modification timestamp, and the context of its use is lost.

The automatic nature of tracking information usage and integrating information across devices in InfoMesh, simplifies some of the effort required for managing and synchronising information consciously, supports work completeness and

continuity, and eliminates device-based information isolation. Aran can work away on his activities, letting InfoMesh track and collate his work behind the scenes. Now, he has access to a compiled and annotated information trail with rich, associated content at any time, through any of his personal devices. When Aran uses the archive functionality every month, he further has access to his archived information as the original annotated trails with the work context intact. This allows him to retrieve information using all of the various contextual cues, instead of relying solely on his memory to locate documents or notes.

PDA Activity View: On his smartphone, Aran's work is tracked as part of various activities behind the scenes. However, the work details and information items are only updated to the information repository (and added to the views) once Aran synchronises the device with his desktop. This is due to the current limitations of the PDA's ability and capacity to generate views, and the subsequent limited implementation of the InfoMesh Presenter on PDAs. As illustrated in the previous task scenario, Aran's use of activity views on his smartphone is often on the go and incidental. He appreciates having that access, as he can jot down ideas, look over notes or sketches, and browse for information as part of an activity, even when all he has with him is his smartphone. As the material is later synchronised to his desktop and incorporated into his activities and information repository, he will not lose track of the work and ideas.

Further scenarios of use: InfoMesh activity views lend themselves to many different types of usage, from activities that track project work (e.g. preparing a presentation, writing a report, developing a product design or web-site) to hobbies, ongoing home management and travel planning tasks (e.g. learning a new language, digital scrap-booking, tracking online purchases, planning a family trip). For all these kinds of work, the activity view provides a way to log work, assess progress, depict phases and changes in work, see previous and current states of work, interpret information relationships, and so on. They also support information sharing and social navigation in new ways, by helping people share their entire annotated information trails that others can follow and extend. For example, Aran can share an activity view of his trip to Queenstown with his friend Coen, with his research into hotels and activities, the places he visited and photos.

Coen could then use this view and the underlying research and experience as a starting point for his own trip planning.

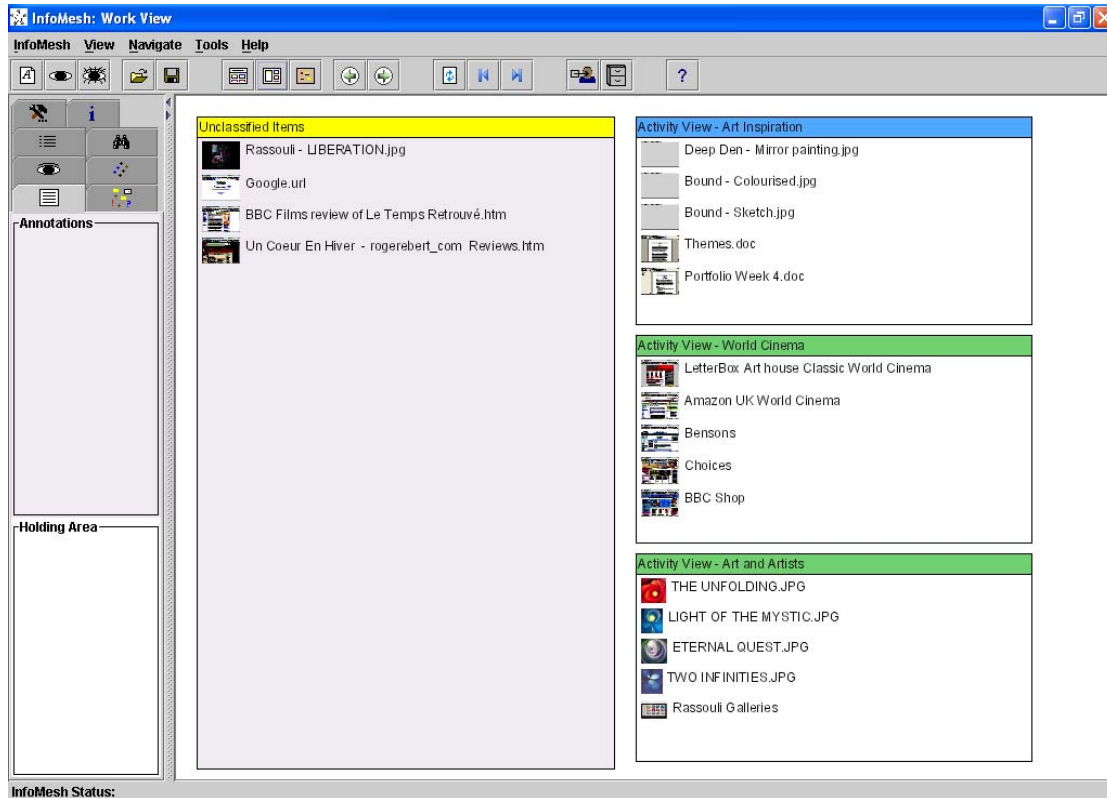


Figure 5-16: Aran's work view

Task scenario for working on multiple activities

Aran was browsing online through his favourite web-sites to find some recently posted artwork and foreign film reviews, specifically items that would strike him as interesting and stimulating. His goal was two-fold. He wanted to find artwork to peruse and perhaps review later, and films to watch out for. At the same time, he wanted to generate ideas for his portfolio work from things he looked at. Consequently, Aran switched to the Work View and opened up pockets for his 'Art and Artists', 'World Cinema' and 'Art Inspiration' activities. The 'Unclassified Items' pocket fills with various information items, as he visits numerous web pages, and saves images and reviews. From time to time, he drags items from the 'Unclassified Items' pocket to the different view pockets. Some of the items belong in two activities, so he drags them across to both. He also flags and annotates any items he drops into the 'Art Inspiration' activity with notes on ideas, techniques and perspectives of interest. When he next works on the activity, he would be able to review and work on those ideas. Aran deletes a few remaining items in the unclassified items pocket at the end of his browsing session, as they are ephemeral and not of interest to him. He then clicks on the "Art Inspiration"

pocket's title bar to go to the activity's view, to continue work on his portfolio.

Work View: When Aran works on several activities at the same time, such as browsing through his favourite artists' new work and writing artist reviews for the Scale art e-zine, he uses the **Work View** (Figure 5-16) to manage the documents he creates and collects for these activities. The screenshot for the previous task scenario shows that Aran has pockets open for several related activities, namely 'Art Inspiration', 'Art and Artists' and 'World Cinema' during his browsing session. He can switch to the overview anytime when he wishes using the toolbar buttons or to a specific activity view using the pockets. He can also use the back and forward buttons on the toolbar (similar in function to those in web browsers) to go between different views he has opened during the session.

5.2.3 SOCIAL VIEW: 'WRITER'S CORNER'

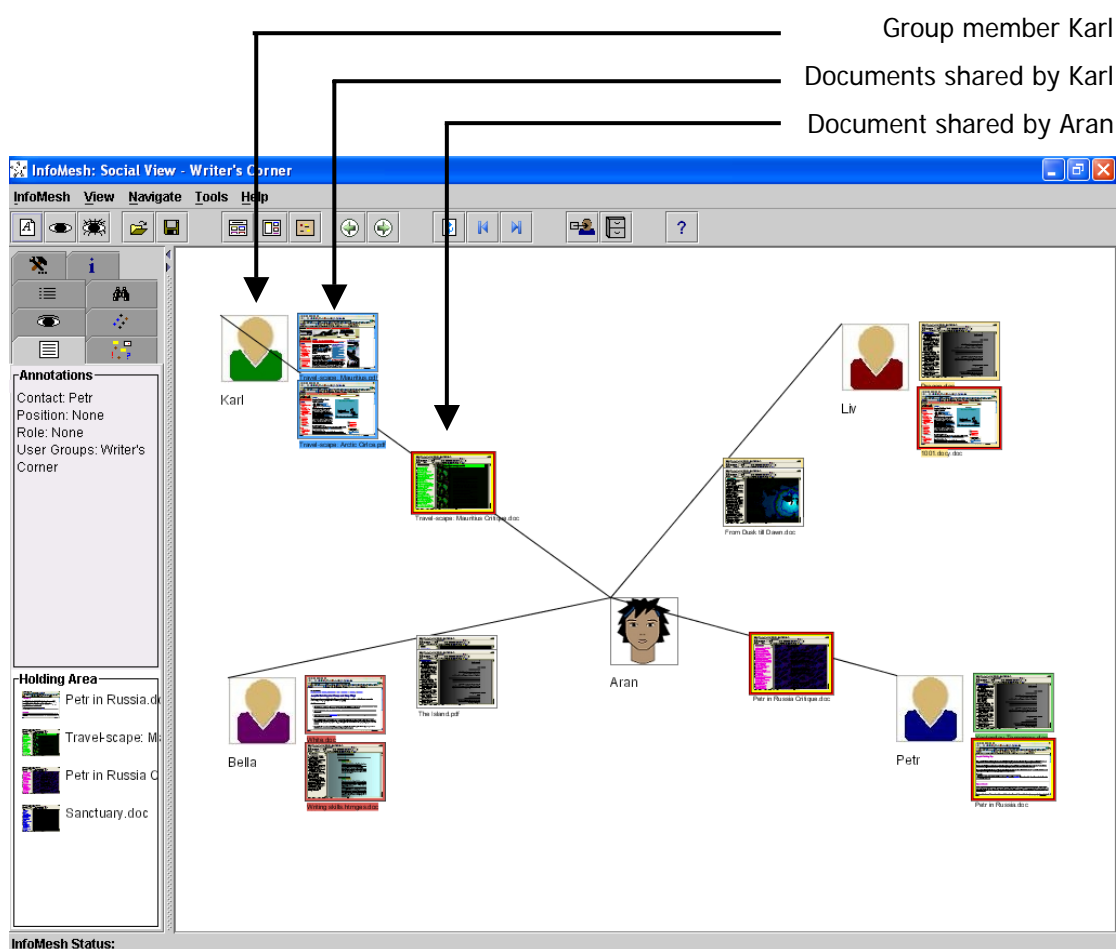


Figure 5-17: Social View for Aran's "Writer's Corner" activity

Activity scenario for “Writer’s Corner” activity

Aran is part of the ‘Writer’s Corner’ group. The group shares short stories and poetry with one another for comments and critique, as well as any written pieces or art they find that sparks an interest. Aran has an interest in literary writing, to sharpen his writing skills for maintaining his blog and writing his monthly column for Scale e-zine, but also especially as he is interested in exploring and inspiring his graphical art with ideas from his writing. With the ‘Writer’s Corner’ activity, he tracks the work he and his group members (Petr, Bella, Karl and Liv) share and critique, with notes on any ideas for his artwork or further writing tasks. The Social View of the activity allows Aran to see documents according to who authored them and who he shared them with. When he wishes to see all the material they’ve looked at and shared over time, he switches over to the chronological activity view.

Aran uses the **Social View** (Figure 5-17) for many group-based activities, as this view presents a people-oriented contextual view for any kind of collaborative activity. He can view documents authored or shared by individuals in a collaborative group graphically, according to each of these group members. The social view is usually associated with an activity and relevant user group, as it is here.

View Content: Aran’s social view workspace has the familiar information item titles and thumbnails, supporting colour-coding and annotations. As this is Aran’s personal information space, he is at the centre of the view and all documents authored and shared are seen from his viewpoint. Other members of Aran’s group are represented by their photos and names, and are spread around his photo. Documents they author and share with Aran are listed right next to them, while items that Aran authors and shares with each group member are listed alongside a line that stretches between Aran and the respective group member. Karl has for example authored and shared two travel-related write-ups with Aran, which are listed alongside Karl’s photo. Aran has sent Karl a critique of his travel write-up on Mauritius, which is listed alongside the line linking Aran and Karl.

Like with other views, Aran can pan and zoom across the social view workspace, to either get the entire picture of the group’s work or to zoom in on particular individuals and the items shared by or with them. At any time, Aran can also use

the navigation buttons on the toolbar, or hit the refresh button to reset the view so that the entire workspace is visible. He can also rearrange the view, by moving group members (i.e. their photos) on the workspace. Their authored documents, as well as the line connecting Aran to them and the associated shared documents, will move with them accordingly.

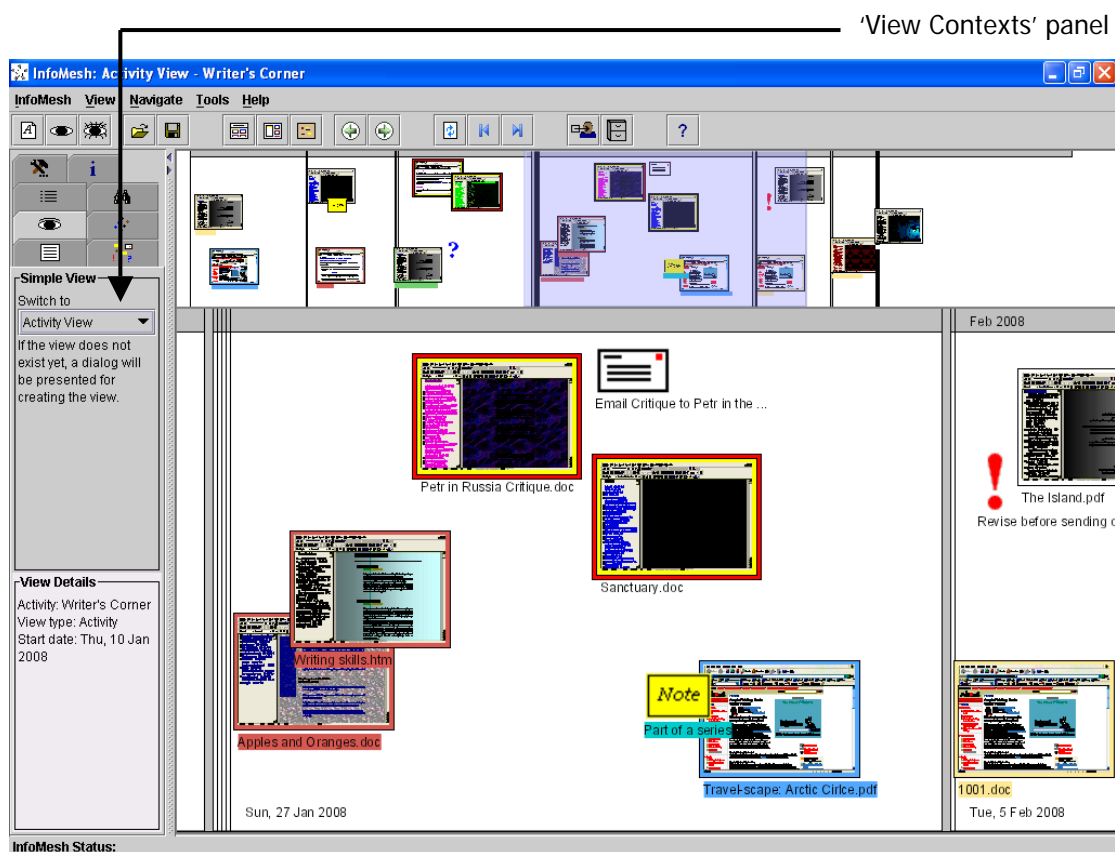


Figure 5-18: Activity View for Aran's "Writer's Corner" activity

Tracking and Integrating Information: Aran can track all his friends and collaborative groups in InfoMesh, by creating user contacts. Contacts (like activities, devices and locations for example) are contextual objects in InfoMesh, and can keep track of names, user groups, photos and contact details for Aran. At any time, Aran can then use item context menus to select and assign these contacts to provide author and sharing details for various items in his activities. InfoMesh incorporates document author and sharing information largely through this user specification. Social views for a particular activity are then generated by using these contacts, author and sharing information, along with the work carried out for the activity. Aran can use the annotations panel in FlexTools to quickly look at a

group member's details (e.g. contact details, roles and user group participation) by pointing at the person's photo in the social view.

View Flexibility: At a glance, the social view allows Aran to see person-document associations for a collaborative activity, where the people associated with a document possibly form the most important context, more than activity, time, location or device. He can infer who has shared which documents, specifically consider an individual and corresponding shared items, review the work done as a group, and decide what his next task or action can be in the collaboration.

Aran's social view (a simple view) is associated with his 'Writer's Corner' activity, and as such Aran can switch to the activity's corresponding activity view at any time. This flexibility is an important aspect of InfoMesh. Each context affords a different perspective on Aran's activity, allowing him to make use of that context (like time and people) and interrelated visual cues to quickly make inferences, interpret activity work or item associations, retrieve information and continue work.

Aran can switch between different context views for an activity by using the 'View Contexts' FlexTools options. As each activity automatically has an associated activity view, Aran only needs to select this view from the drop-down box for InfoMesh to bring it up. Suddenly, Aran has access to the chronological 'story' of the intermittent work carried out by the group as part of their writer's corner (Figure 5-18). He can immediately see how active the group has been over time, what has been shared in the last week, and what he was last working on as part of the group so that he can resume that work. He can return to the social view and its person-document associations, by switching back to it using the same FlexTools option. The 'View Contexts' panel also lists general details about the view, including which activity it belongs to and when the activity was started.

Similar to the activity view, the social view provides more personalisation and context to Aran's work than the hierarchical listing of the shared documents can. With the additional flexibility of switching between contextual views like the activity and social view, InfoMesh offers more perspectives on Aran's work and the same underlying items.

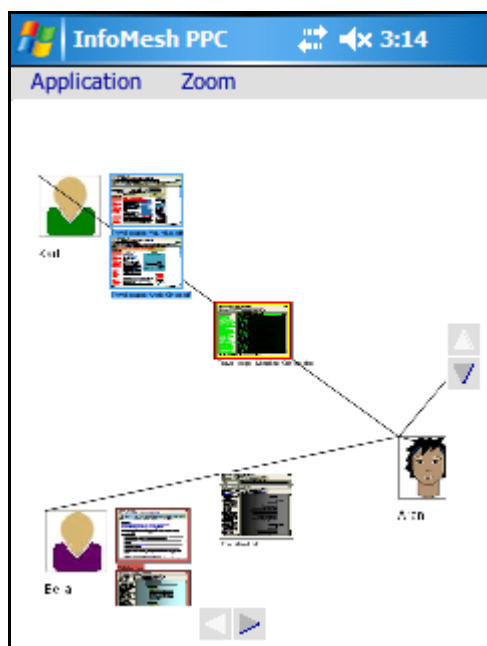


Figure 5-19: InfoMesh Social View on PDA

PDA Social View: On his smartphone, Aran uses social views largely as a reference, a reminder or for taking a quick action when speaking to or meeting up with friends (see Figure 5-19 for a screenshot of the social view on a PDA using view zoom level 50%). As the view instantly shows him person-information relationships, he can see what has been shared and what needs his attention.

Further scenarios of use: InfoMesh social views are suitable for any activity that involves people, whether it is in support of collaboration (like Aran's 'Writer's Corner' activity), online groups for support or shared hobbies (e.g. local e-trading or home budgeting groups that keep each other informed or share tips), and communication (e.g. tracking family members and their communications). The social view sifts through the considerable distributed and non-specific information and highlights this information according to people and their input. The inherent meaning in this socially oriented view can once again accommodate better understanding of the underlying information items and prove more useful when shared.

5.2.4 MAP VIEW: 'WORLD CINEMA'

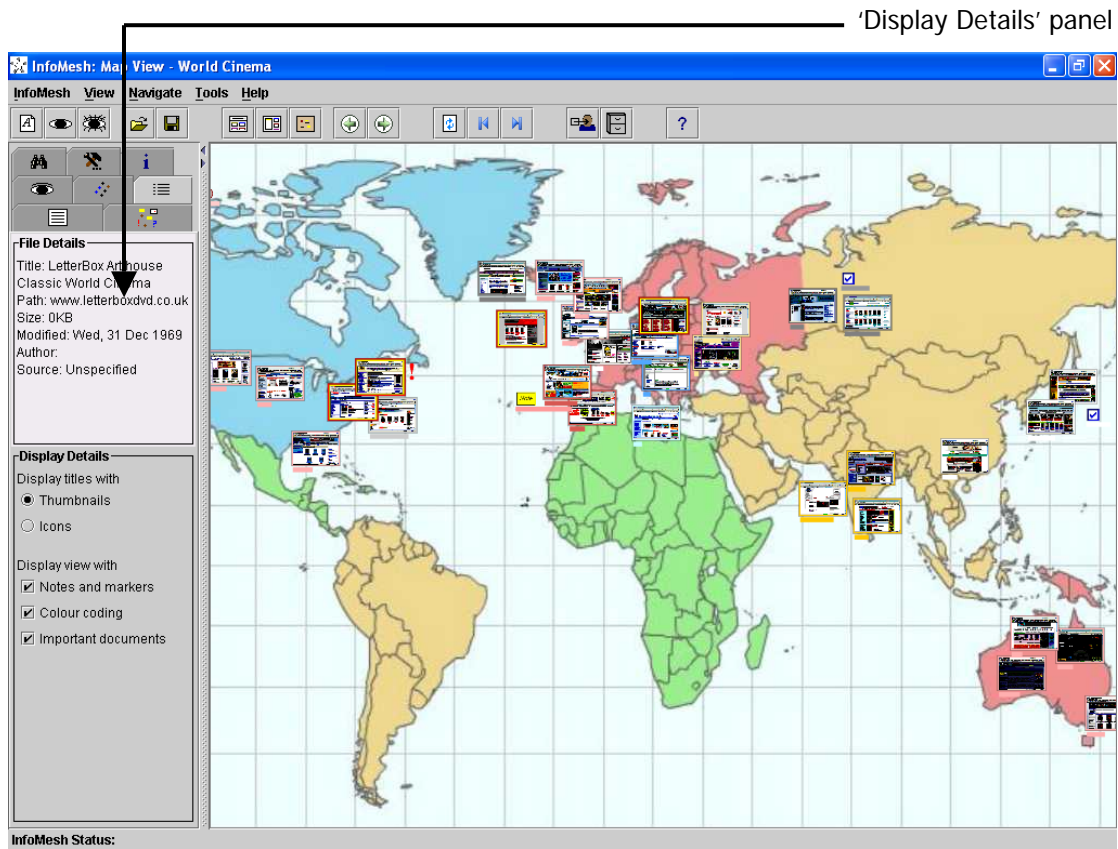


Figure 5-20: Map View for Aran's "World Cinema" activity

Activity scenario for "World Cinema" activity

One of Aran's big interests and sources of inspiration is world cinema. He watches movies from different parts of the world, in various languages, as long as their subject and style interest him. With access to non-mainstream movies limited in his area, he mainly tracks down movies through several movie review web-sites and orders many from online stores in or near their country of origin where they are available. As his various movie review web-sites and online stores are tied to a country or region, he's organised them as part of a map in his "World Cinema" activity, with bookmarks, notes and wish-lists. He felt that this way, he'd be able to quickly zoom in on review sites or stores in an area for a film he heard about or was considering getting, or the next item on his different genre and language based wish lists. As time progresses, the activity view for 'World Cinema' would allow him to see what he has been recently interested in when reading film reviews, to know which movies he may try out next.

The **Map View** (Figure 5-20) provides (physical or virtual) location-oriented context to information items in an activity. Aran can essentially select or create an

underlying map (e.g. country, building or category map), and arrange information items according to the location of relevance.

View Content: The map view too presents items by their titles and thumbnails, with support for grouping, colour-coding and various workspace and item annotations. The view's unique characteristic is its support for an underlying map. Here Aran has used a colourful map of the world to arrange his region and language-based review sites and stores. He can create and add new customised maps to InfoMesh for use with map views, which allows him to create a floor plan for a gallery exhibit or a theme-based category map for artwork from his portfolio. Aran can use the 'Display Details' FlexTools panel shown in the figure to view the file details for any item by pointing to the item when the panel is open. The panel also allows him to change the display details for the view to, for example, display only item icons rather than thumbnails or filter out notes and markers. Aran can navigate the map view with the same tools as used with the other context views seen so far. He can pan and zoom across the map view and also use the various toolbar navigation options.

Tracking and Integrating Information: As with social views, information accessed for the 'World Cinema' activity is automatically added to the activity and the view, i.e. information items are added to the map view, and behind the scenes, to the corresponding activity view as well. Aran can then arrange items according to their place on the map, and annotate them and the workspace. Once a context view, such as the social view or map view, is created for an activity, InfoMesh will continue to add items to all the created views when Aran works on the activity. That is, if Aran has the activity view open for 'World Cinema', InfoMesh will continue to associate information items with the map view for the activity as well. Therefore, when Aran switches back to the map view, those new items are also available from there.

View Flexibility: The map view helps Aran quickly spot location-information associations for an activity, specifically of use when location becomes an important context for the activity. When he's conceptualising (e.g. an arrangement of art for a gallery exhibit), browsing through (e.g. reviews for the latest film

releases in France) or retrieving (e.g. favourite art galleries in a particular city) location-based information, the matching visual contextual cues can afford a more natural, implicit way of viewing and accessing that information.

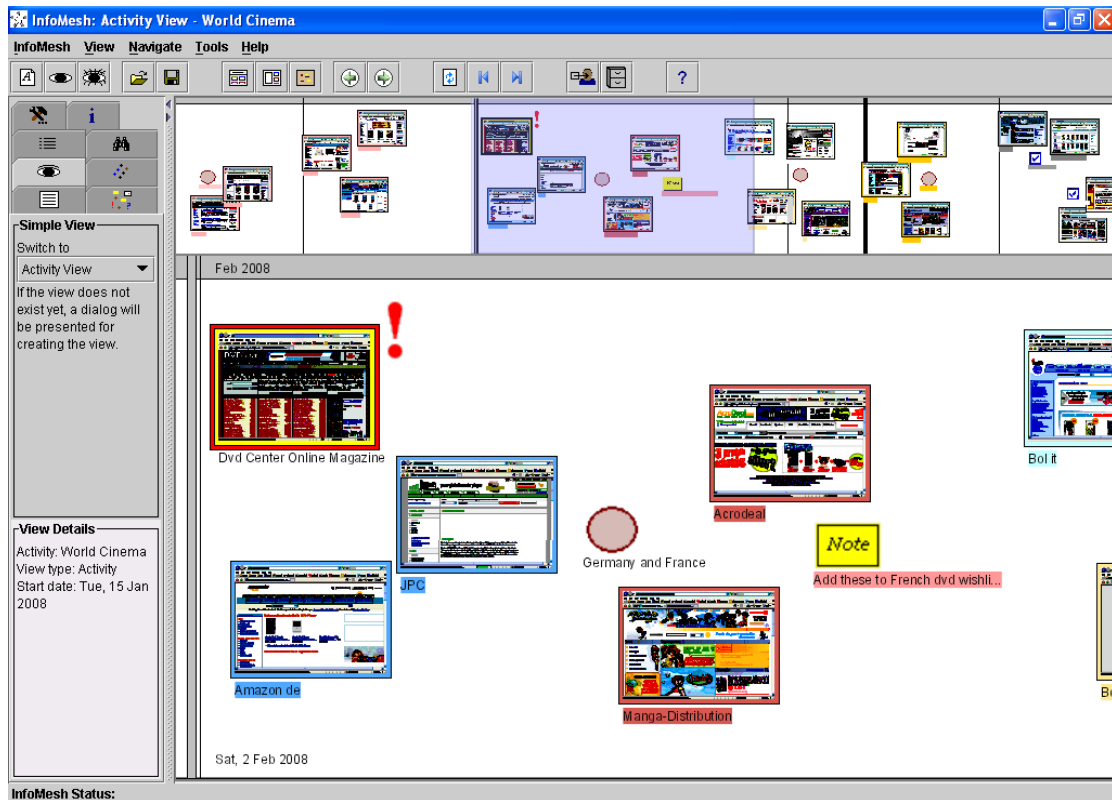


Figure 5-21: Activity View for Aran's "World Cinema" activity

Task scenario for switching to an activity view for "World Cinema"

Aran finished reading some film reviews, and remembered a review from two weeks back for a quirky anime that he thought he might rent out that night. He had the evening free, so thought a movie night in with a couple of friends would be great.

Aran has the map view open, and switches to the activity view using the FlexTools panels. The activity view opens up on the current day and Aran pans to two weeks back. He only had two sessions last week when he looked up reviews, and immediately spots the review he was looking for as he had marked it with a big star as usual to indicate his interest. Later he heads out to get the movie and some snacks for the night.

As with social views, Aran's map view is associated with a specific activity and so he can switch between them with a single-click using FlexTools options. Figure 5-21 shows the activity view for Aran's 'World Cinema' activity. Here the personal, chronological activity context allows him to use time, time-based

information associations and markers as retrieval cues. This flexibility allows Aran to adjust the views on his activity to match his work context or information needs.

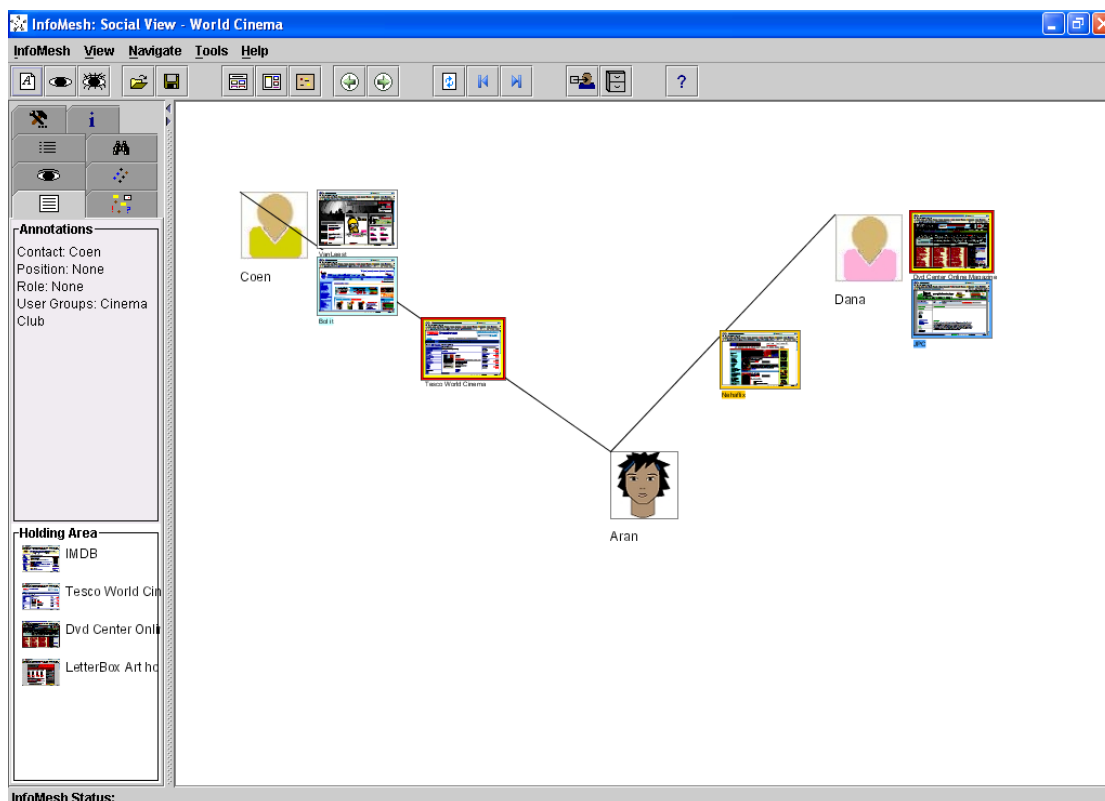


Figure 5-22: Social View for Aran's "World Cinema" activity

Task scenario for switching to a social view for "World Cinema"

Aran is using the map view for his "World Cinema" activity, looking through several online DVD stores in the UK for a particular movie release. Coen had shared a site with him at some point, telling him that the store listed many European releases at a great price. Aran switches to a social view for the activity to find the site. Aran opts to say yes when InfoMesh asks him whether he would like to create a social view for "World Cinema", as one does not exist as yet. InfoMesh then creates and displays the view. Aran quickly spots the two sites that Coen has shared with him, and visits the Dutch site that Coen favoured.

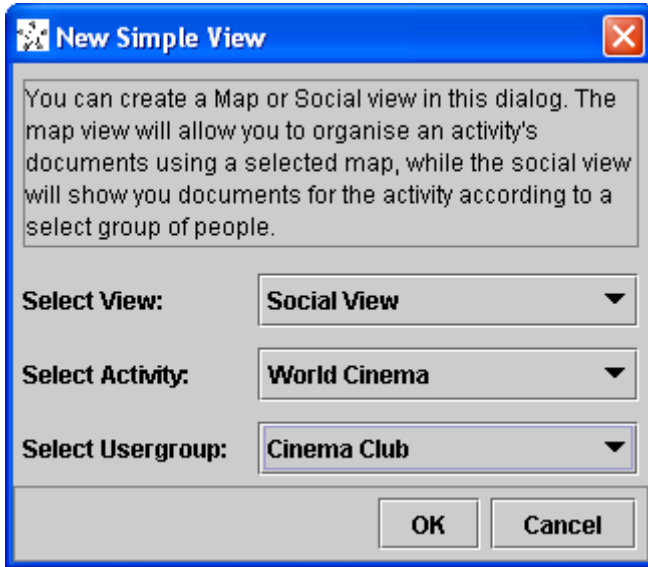


Figure 5-23: New Simple View application dialog

For each activity, Aran has the choice of three simple views. The activity view is always created for each new activity. Aran can then also create a map view and a social view if he finds the corresponding contexts useful. In the previous scenario, Aran chooses to create a social view for “World Cinema” (see Figure 5-23 for the ‘new view’ dialog for simple views), whereby InfoMesh retrieves the information items that were shared with or by Aran as part of the activity and its corresponding user group ‘Cinema Club’. At once, Aran can view the activity’s information items from the perspective of his friends and their communications (Figure 5-22). As such, this allows him to use his activity’s social context for answering certain information queries that he specifically remembers as relating to a person, as opposed to time, locations, folders and so on. Once again, that flexibility allows him, within limits, to adapt the view he has of his information space to his queries and work context.

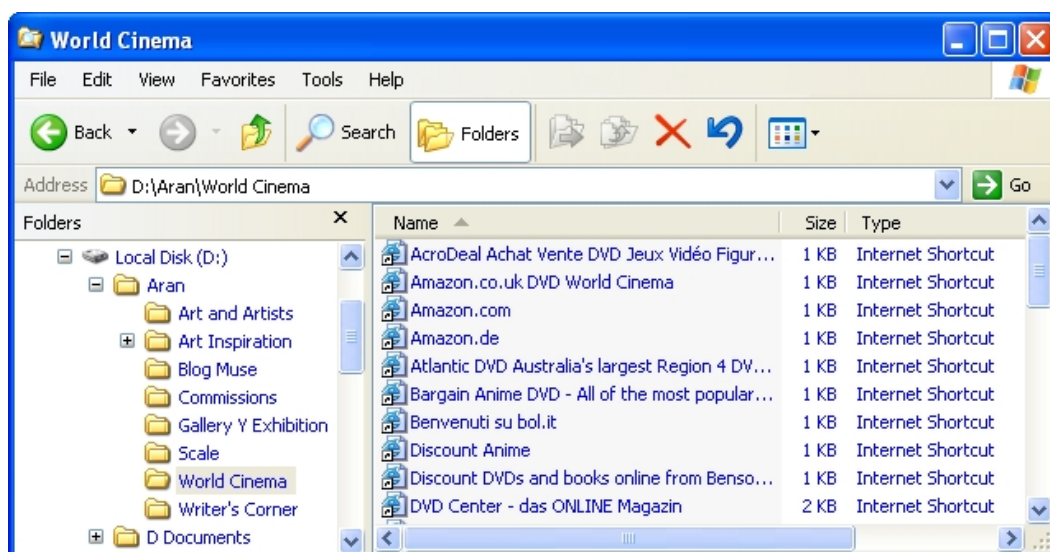


Figure 5-24: Hierarchical folder view of Aran's "World Cinema" files

A hierarchical view of the same underlying bookmarks (as in Figure 5-24) on the other hand is missing these contexts of locations, people and temporal associations, as well as the personalisation of view spaces through annotations and striking arrangements. Hierarchical views on information complement InfoMesh views. However, for many types of information, using the user-specific contextual associations that occur in information-interaction, can provide a more personal and natural way of perceiving, interpreting and making sense of that information.

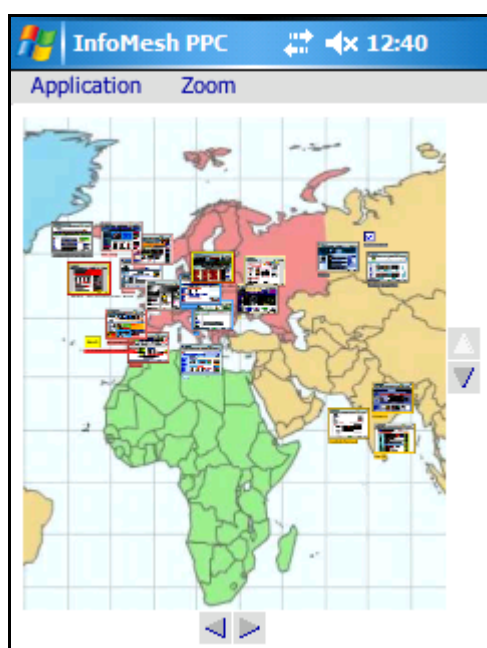


Figure 5-25: InfoMesh Map View on PDA

PDA Map View: Aran finds map views useful on his smartphone for when he is making use of location information for the real-world component of an activity. (See Figure 5-25 for a screenshot of the “World Cinema” activity on a PDA using zoom level 50%.) For example, he might plot out art galleries and local artist studios of interest to him in a city he is travelling to, with specific notes on paintings or sculptures to look at and artist profiles. The map view on his smartphone can be a reference for him on the go when he’s visiting the city. Aran can scroll through the view, zoom in and out to remind himself of something of interest or decide on his next action.

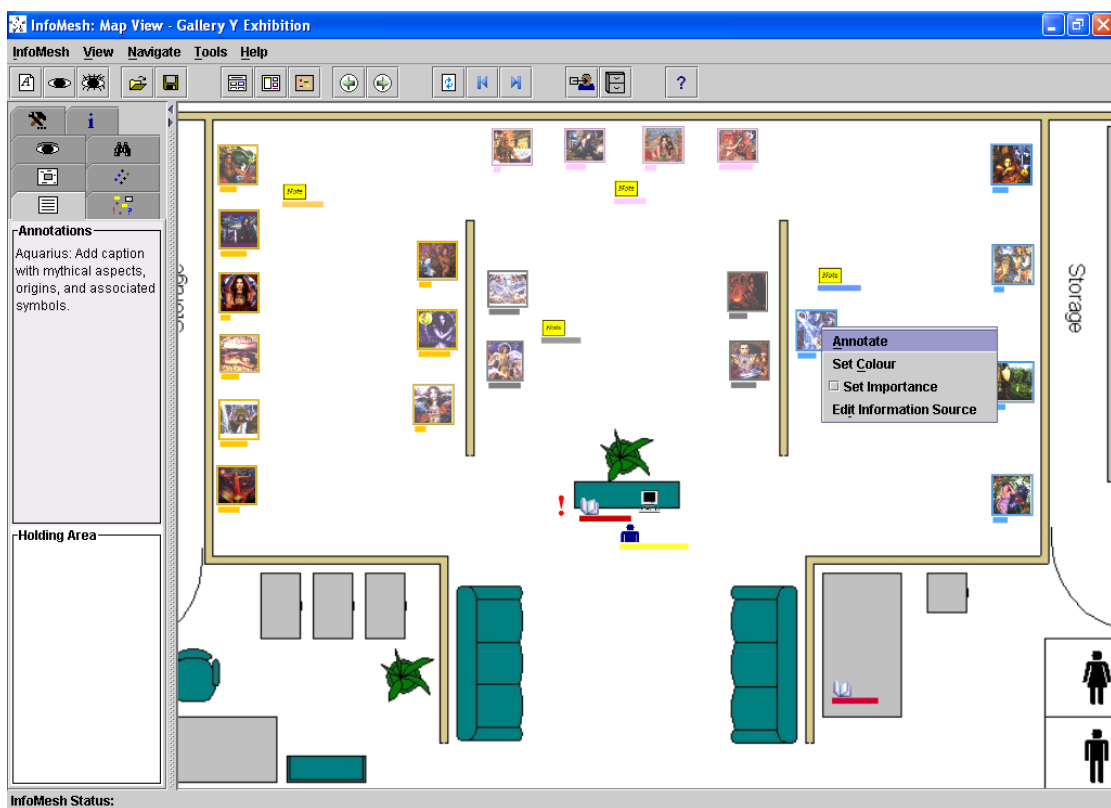


Figure 5-26: Map View of Aran's “Gallery Y Exhibition” activity, with item context menu selected

Activity scenario for “Gallery Y Exhibition” activity

Aran has nearly completed his new portfolio of work, and will be holding an exhibition at a small local gallery in a month and a half. He’s planning to show a major segment of his portfolio, and is going to be managing the art and thematic arrangement and flow himself.

Aran has created a map view to help him with the art arrangement at the gallery, as part of a “Gallery Y Exhibition” activity. He’s using the gallery’s layout he received by

email as the underlying map. He uses the layout to arrange and re-arrange his artwork according to the gallery spaces and measurements, as he finalises his portfolio and selects the artwork he wants to display.

Aran updates the art layout on the map view on different occasions, using the pan and zoom functionality often to survey the arrangement, adding notes and ideas alongside for flyers and captions, until he's slowly satisfied with the layout. When meeting up with his friend Dina, he briefly goes over the layout with her on his PDA. As the date for the exhibition nears, he checks the exhibition activity and map for a final revision. He emails his art arrangement to the gallerist, and prints out a few zoomed-in copies of the view for himself and his friend for when they will transport the artwork and prepare the exhibition.

Further scenarios of use: InfoMesh map views can be applied to a wide variety of activities, as many activities can have a spatial component. These activities can include physical locations, building or floor plans, or virtual category maps and the like. Aran can add his own map or layout to a map view and associated activity, as seen in the previous scenario where he used a gallery layout (Figure 5-26).

Map views based on locations can be like Aran's 'World Cinema' activity, or incorporate a real estate map for tracking houses on sale in the neighbourhood, a world time zone map indicating where different family members live, a world map for a fantasy novel with notes and history, and so on. Similarly the activity view mentioned earlier that Aran shared with Coen regarding his Queenstown trip, could have an associated map view. The map view could capture his trip pictorially for future recall or sharing with family, by presenting Queenstown and environs with the places he visited, activities he took part in and photos he took.

Map views using building and floor plans or category maps, like the 'Gallery Y Exhibition' activity can be tailored to suit specific needs. They can include a house construction plan with the elements that require work; lay-outs for offices or labs and the documentation, designs or products they produce; or a mind map of ideas and their fleshed out documentation and designs.

5.2.5 ANNOTATING AND QUERYING THE INFORMATION SPACE

InfoMesh provides Aran with views onto his information space according to his activities and contexts such as time, people and locations. Alongside these views

are a set of tools that Aran can use to manipulate views and view content further, by adding various annotations or by altering views to query the underlying information space. Aran can access these FlexTools through the panels on InfoMesh as described before.

ANNOTATING THE INFORMATION SPACE

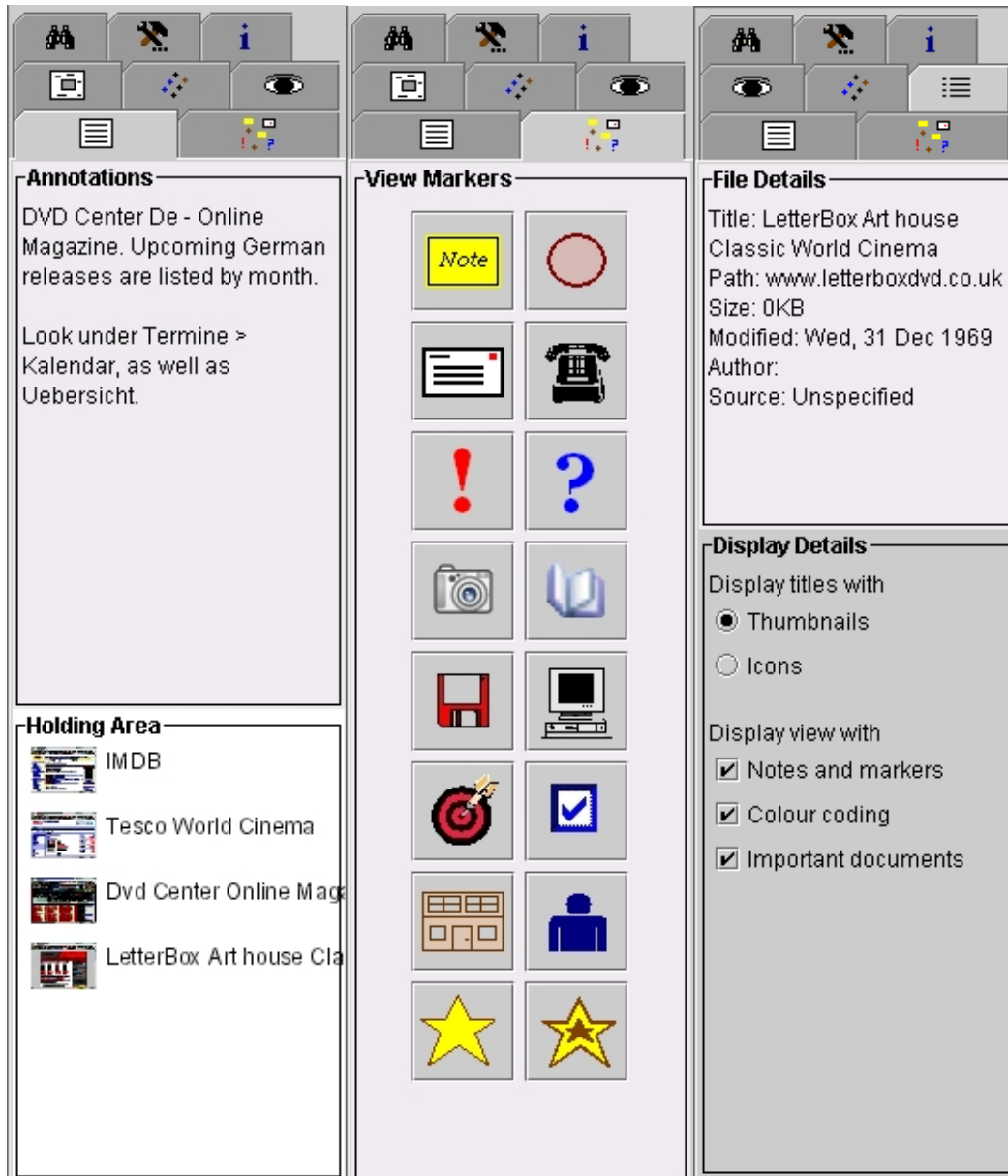


Figure 5-27: FlexTools panels for Annotations, View Markers and Display Details

Task scenario for annotating information items

Aran visits a German web site from time to time as part of his interest in 'World Cinema' to review new German DVD releases. He often has a hard time finding the

calendar-based listing of releases on the web site however, so he has added an annotation to the bookmark in his activity to explain where to look. Every time he hovers over the link the annotation is visible in the FlexTools panel, reminding him of where to go. Aran finds the site very useful to get updates on European releases, so he has also flagged it as an important item in his activity. Now the link displays a bolder colour in the view and appears in the holding area in the FlexTools panels, giving Aran quick access to the site as well as other information items he has flagged as important for the activity. Aran generally uses the context menu that appears when right-clicking on information items, to colour-code, annotate and flag those items as important.

Annotating the information space through FlexTools (see ‘Annotations’ panel in Figure 5-27), and through workspace and item context menus, allows Aran to personalise and detail his information space according to his ongoing work context and information usage. Colour-coding and grouping are available to both information items and view markers, and Aran can specify various contextual details for items (e.g. author, sharing, location and source information) that can be queried and in part used to display context views. Details such as item titles, preview thumbnails or icons, important documents, colour-coding, grouping and item annotations, can enrich Aran’s perception, navigation, interpretation and access of the information presented in the views on his information space.

Task scenario for adding view markers

In his portfolio activity ‘Art Inspiration’, Aran uses markers to indicate changes in the activity landscape, such as milestones he’s reached or his current goals. He often uses specific colour-coded markers to indicate phases of his work or actions he needs to take, and symbols like exclamation and question marks to indicate priority and questions he has.

Aran further uses workspace notes and keyword anchors to provide information about segments of the workspace. For example, he adds keyword anchors to groups of artwork he views, where he lists artist details, styles and ideas that come to mind. He can use those keywords and details at any time to query or scan and locate those groups of information items.

Aran uses a variety of markers through FlexTools to annotate his views (see 'View Markers' panel in Figure 5-27). Action markers (such as email, phone, building or device icons) and their associated messages act as reminders for things he needs to do, such as email someone a document or meet up with a friend. Aran uses other markers as symbols (e.g. exclamation, question, target icons) to remind him of priority items or goals he has and so on (e.g. he uses stars to indicate items of interest in many of his activities).

Markers can also record changes in the activity landscape by signalling a new phase or altered direction in work, milestones and goals, or otherwise divide up a view in segments. By creating and using these landscape markers, Aran is able to create an activity space that can be scanned and navigated according to this extra layer of meaning. Markers such as workspace notes and keyword anchors add further useful snippets of information to the ongoing activity work.

As all these markers stand out visually and as Aran can search on the marker content, he can use the markers and the corresponding written reminders, goals, notes and keywords to retrieve associated information items in the information space.

Task scenario for viewing file details

Aran uses the 'File and Display Details' FlexTools panel to view file details for his 'Letterbox Art house' film site. He can access various details for an information item such as size, modification date, author and source information, by pointing at the item in the view (in this case the link to the Letterbox film site).

Task scenario for sharing a view and changing view display details

Aran's friend Coen has a growing interest in foreign cinema and has asked Aran for review sites that he finds useful. Using the 'File and Display Details' FlexTools panel, Aran decides to switch off the notes and markers on his 'World Cinema' map view, as he wants to share the view with Coen and does not want to pass along his personal notes and comments with it. He leaves the colour coding intact, as he's colour-coded items based on language and Coen might find that useful. Using the 'Share View' button on the toolbar, Aran sends a detailed representation of the map view to Coen by email, so that he can use it to look up review web-sites and DVD stores according to language and region.

Aran can view file details for information items and change which items are displayed in InfoMesh views using the ‘Display Details’ panel in FlexTools (see Figure 5-27). There may be views where certain elements are unnecessary or undesirable. For example, colour-coding or view markers may not be useful if Aran chooses to create an advanced view, which incorporates items from multiple activities. In that last case, the markers and colour-coding may no longer carry information that is needed for the new work context and simply take space. In the previous scenario, Aran chose to hide his personal notes and markers as he was planning to share the view with a friend.

The rich, contextual views and information trails that InfoMesh presents can be useful in supporting social navigation. By sharing his map view of his ‘World Cinema’ activity with Coen, Aran helps Coen explore his new interest in foreign films by making use of and building on Aran’s discoveries, bookmarks and information classification. As the classification according to location context and colour-coding according to language is left intact, Coen can make sense of the information more readily than if the bookmarks were passed simply as a list of URLs. InfoMesh only supports static view sharing in the current implementation, but ideally would support views that give others access to the underlying links or information items according to the specifications of the users sharing the views. By uploading the large-sized map view of his “Gallery Y Exhibition” to his blog, he can also let visitors browse and view his artwork online exactly as he organised it for his exhibition. Sharing these detailed, graphical views opens up new ways of supporting social navigation online and offline, in ways that can add more individuality and meaning.

Task scenario for archiving information

Aran archives his personal documents every week, especially to keep his graphic designs and ideas safely backed up. At the end of every week he uses the ‘Archive InfoMesh’ button on the toolbar to create an archive of his entire information space in a location he specifies on his external hard-drive. InfoMesh copies across all activity and view details, and their annotations to the location, along with the underlying information items.

The rich, associated content displayed by InfoMesh can be useful in generating personalised, pictorial archives. Aran can keep the entire annotated ‘story’ of his activities intact with his work context, trails of information-interaction and various contextual relationships, rather than simply the documents he’s collected or created.

In the current InfoMesh prototype, InfoMesh archives Aran’s information space by copying across its related web of annotated information, activities and views, as well as the folders that the system is monitoring. If Aran’s device crashes, he just needs to copy back this information (i.e. copy InfoMesh data into the application’s data folder and copy across his document folders). InfoMesh will present all his activities, views, contexts and annotations as they were at the time the information was archived.

The benefit of keeping these pictorial archives is that the ‘diary’ of work and information-interaction will still retain all of the personal and contextual retrieval cues. Rather than relying on item locations and folders, he can use more natural recollection cues (such as activities, time, vivid annotations, people, locations and so on) to navigate, locate as well as make sense of old information. The personalised contexts and trails of information can naturally remind or inform Aran of the context of his prior work, and act as a ‘life-long diary companion’ that brings together his electronic information-interaction uniquely in relation to him.

QUERYING THE INFORMATION SPACE

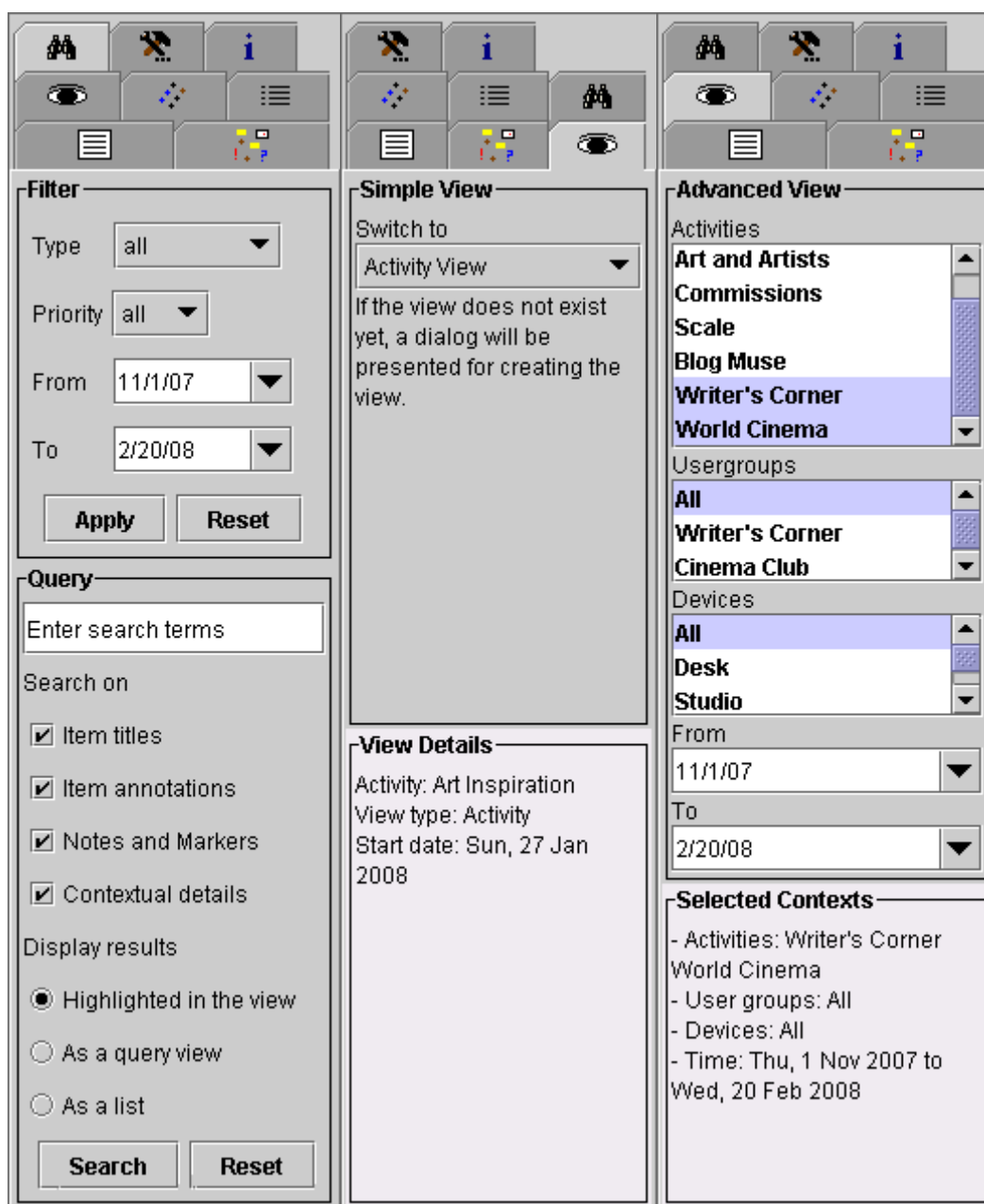


Figure 5-28: FlexTools panels for Filter and Query, and View Contexts (Simple and Advanced)

InfoMesh looks at querying the information space or retrieving information in several ways. Firstly, there is the implicit way of retrieving information according to the basic context of activities, and supporting contexts of time (Activity View), people (Social View) and locations (Map View) for each activity. This mode of finding information centres on viewing and, when needed, swapping between simple views for a single activity, to get different context-oriented perspectives on the information space according to the specific work or information requirements.

Secondly, the visual annotations in the views on the information space (such as colour, item arrangement and various markers) can create striking activity landscapes and act as secondary retrieval cues when surveying the activity space.

FlexTools offers two more ways of querying information by combining traditional keyword searches and filter criteria with view flexibility, namely through the use of filter and query options and advanced views.

Specific filter and query options offered through FlexTools (see the ‘Filter and Query’ panel in Figure 5-28) allow Aran to filter the information space based on certain criteria, or search view content and annotations for specific terms. The results are displayed dynamically through the view by excluding any items that do not match the filter criteria or fading out any items that do not relate to the search terms (the default options for displaying the results). Aran can apply filters or perform searches for both simple and advanced views. These options allow Aran to quickly tweak his view of the information space to suit his current information needs, with the contextual associations still kept intact.

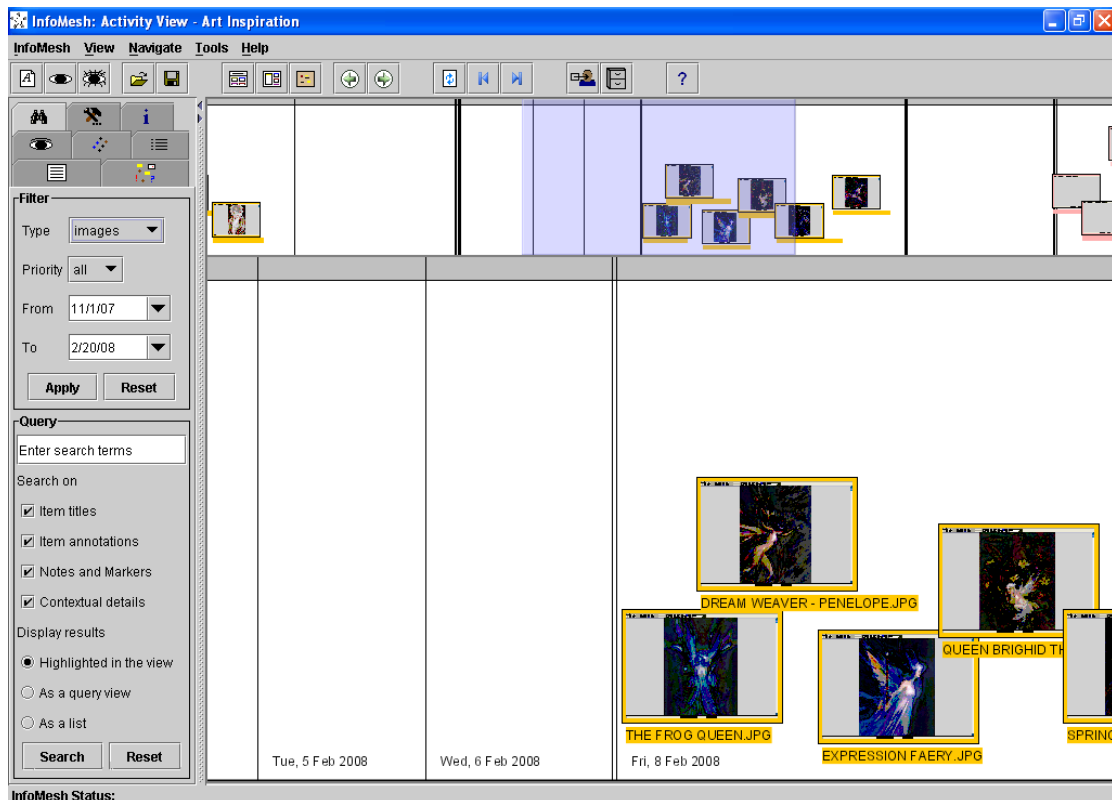


Figure 5-29: Filtered activity view for Aran’s “Art Inspiration” activity

Task scenario for filtering a view

Aran wants to look over the various artwork he has looked at for his 'Art Inspiration' activity. He uses the 'Filter and Query' panel in FlexTools to filter the activity's view to display only images. The filter hides all information items on the view except the image files. Aran simply scans through the activity space reviewing the artwork he's looked at and writing up any notes that come to mind.

InfoMesh offers Aran basic filter options for filtering the view according to document type, priority and time period. The options presented here serve as an example and can be extended to support dynamic queries by utilising sliders for a host of relevant filter criteria.

In filtering views, Aran can target items of interest in his activity space quickly by removing items that are not relevant for the task at hand. In the previous scenario for example, Aran's view is simplified without losing the item associations or temporal relationships for the images he is interested in (see Figure 5-29). Panning across the activity view, he can therefore readily survey and grasp the resulting view space and access the items of interest.

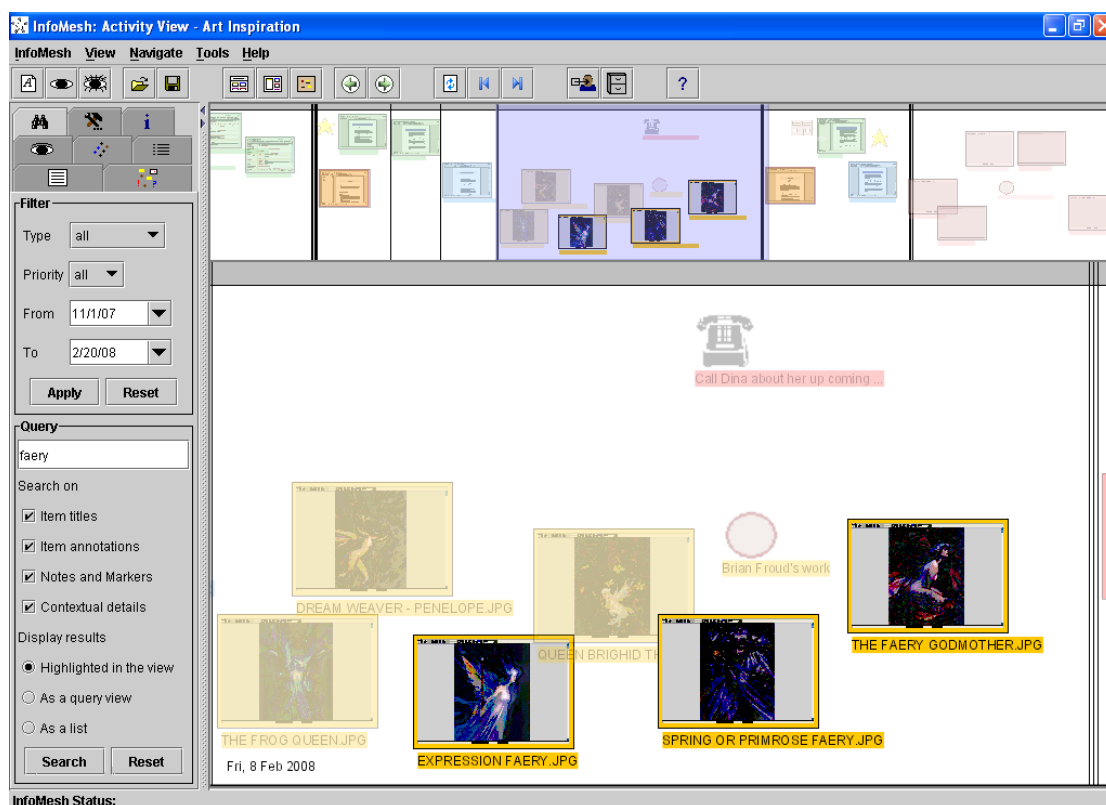


Figure 5-30: Queried activity view for Aran's "Art Inspiration" activity

Task scenario for querying a view

Aran wishes to retrieve a particular faery painting by Brian Froud he had looked at as part of his 'Art Inspiration' activity. He uses the 'Filter and Query' panel in FlexTools to search for the word 'faery' occurring anywhere in the titles and the various view and item annotations, and chooses to view the results highlighted in the view (the default setting for displaying query results). The query lightly fades out all items on the view except those that match the search terms. Aran notices the bright set of thumbnails on the activity timeline and uses the timeline navigator to move to them on the view. The thumbnails are of images that match the query, grouped together with other paintings by Froud that Aran had tagged with a keyword anchor. Aran recognises the painting he wanted from the thumbnails (namely the 'Expression Faery' painting), and opens it up by clicking on its thumbnail. Later on, he hits the 'Reset' button on the panel to switch back to the normal activity view.

Aran can currently use the InfoMesh query options to search for words in item titles, annotations, markers and contextual details (such as source or information sharing information). By highlighting the results within the view itself (Figure 5-30), Aran can query view content dynamically and retrieve information without losing their context and relationships. In this way, InfoMesh queries support direct information retrieval or teleporting by locating a match to the search terms, but also support indirect information retrieval.

In indirect information retrieval or information orienteering, Aran can locate items based on other items that he recollects details about. So, if Aran for example remembers that he jotted down some ideas around the same time as working on his 'Bound' designs, he can use this information to search for the designs to then subsequently locate the ideas he jotted down (due to their chronological proximity on the activity view). In these circumstances, associative or contextual retrieval (whether by activity, time, people, locations, or information relationships and annotations) is enhanced by combining a traditional search tool with contextual visualisations. Incorporating full text searches and more detailed search options for contextual details would augment the query tool further.

InfoMesh further supports applying display settings, filters and queries one on top of another. In this way, Aran can choose to switch off the display of markers in a

social view, filter the resulting social view for a specific time period, and then proceed to query the view according to some search terms.

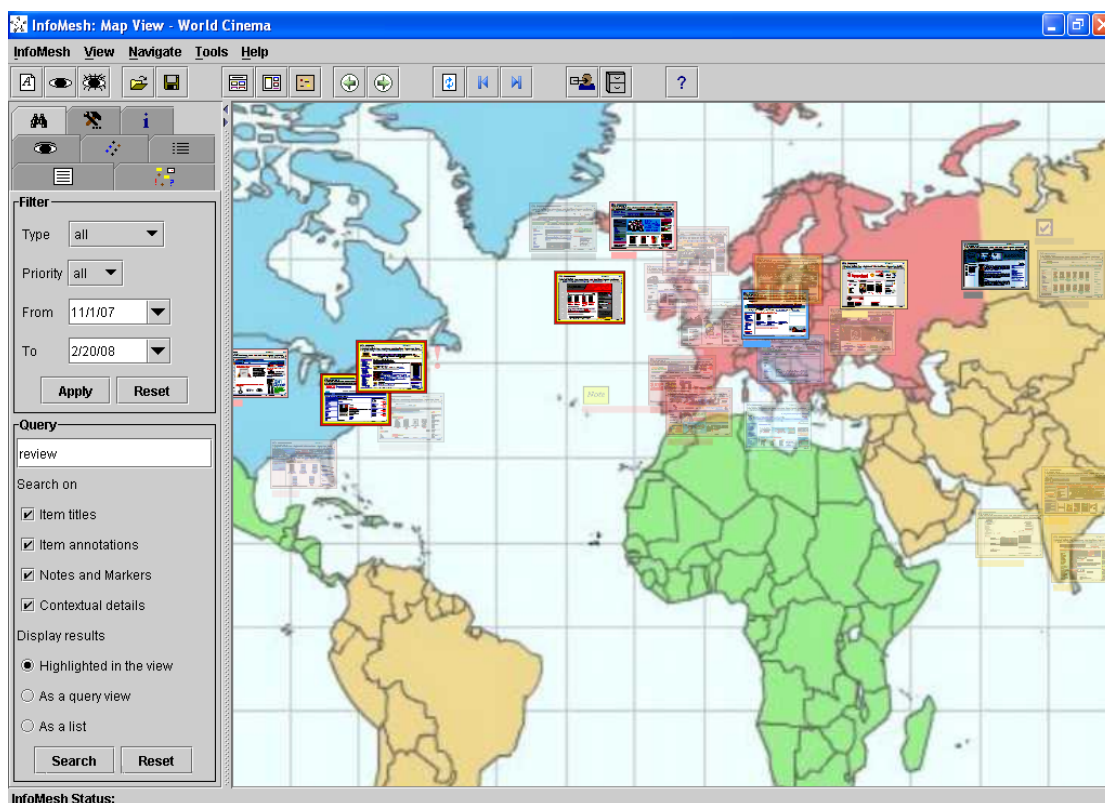


Figure 5-31: Queried map view for Aran’s “World Cinema” activity

Task scenario for querying a view

Aran would like to quickly locate the review sites in his “World Cinema” activity to look over some new film reviews during his lunch break. He often indicates in the bookmark titles or annotations that it’s a review site, so he uses the FlexTools query options to search for the word ‘review’, choosing to view the results highlighted in the view. The query lightly fades out all items on the map view except those that match the search terms. Aran notices the bright review sites among the otherwise faded items in the view space. He zooms in on Europe to open up a British review site and peruses through some new review listings. He doesn’t reset the query, which allows him to access the queried view space exactly as it is when he returns to the “World Cinema” map view on his next break. At that point, he opens up a German review site and browses through some of the newly listed film releases and reviews on that site.

As this last scenario shows, Aran can leave filtered and/or queried views as they are to return to them at any given point in the future (Figure 5-31), as InfoMesh retains the settings across sessions and devices until Aran resets the view’s filter

or query options. In this way, a queried view enables Aran to adjust the view to a subtly changed goal for the activity, highlighting relevant items in the activity space without losing their context, until that goal is reached or replaced at some point in the future.

Keeping adjustments to the FlexTools options (e.g. display, filter or query options) intact across sessions is also of particular use with **Advanced Views**, where Aran can create diverse views on the fly and associate them with a variety of activities and contexts. He can save these views on the information space, each of which can provide a targeted perspective on the underlying information items.

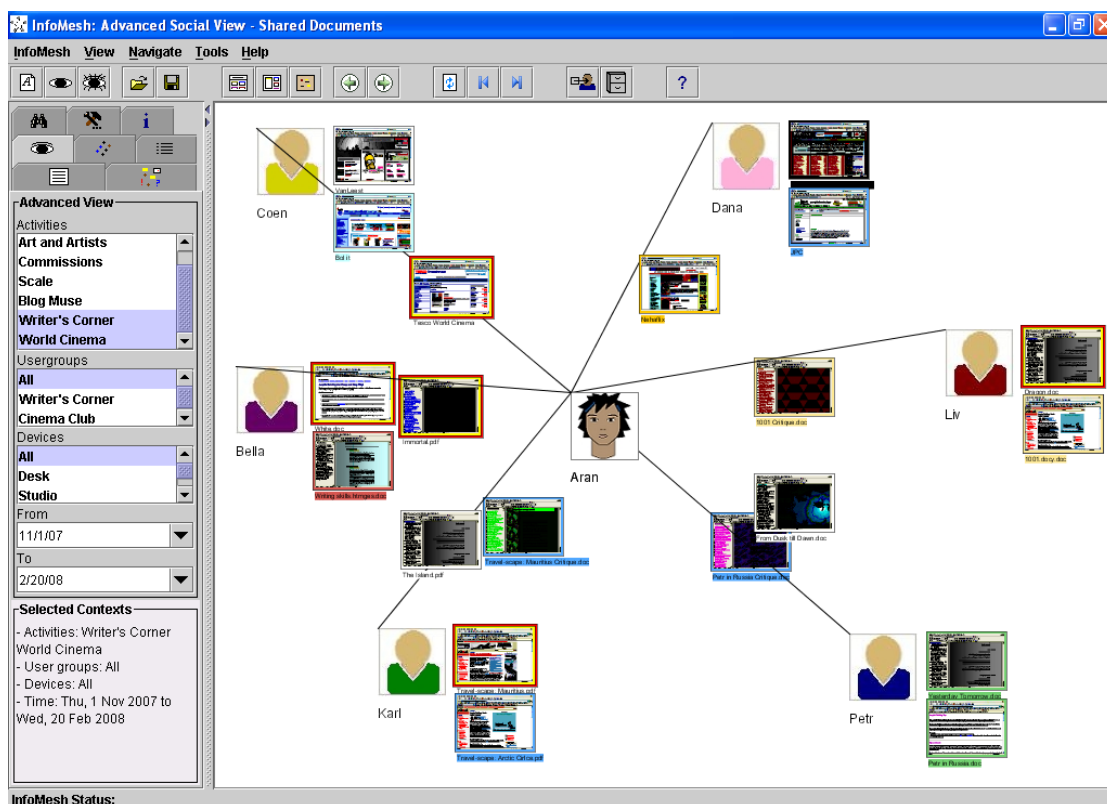


Figure 5-32: Advanced Social View “Shared Documents”

Task scenario for using an advanced view

Aran wants a quick overview of the documents he’s shared with his friends since he started using InfoMesh. He uses the ‘New Advanced View’ button on the toolbar to create an advanced social view called ‘Shared Documents’. He includes only his social activities ‘Writer’s Corner’ and ‘World Cinema’, and includes all user groups he is a part of and all his devices. Combining these activities and contexts, InfoMesh generates an advanced social view with the applicable contacts and information items. Aran rearranges some of the contacts on the view for clarity and looks over the documents he

and his friends have shared. As time goes on, he intermittently checks up on the view to survey documents shared, adding other activities to the view through the 'View Contexts' panel, filtering it according to time or querying the view when needed.

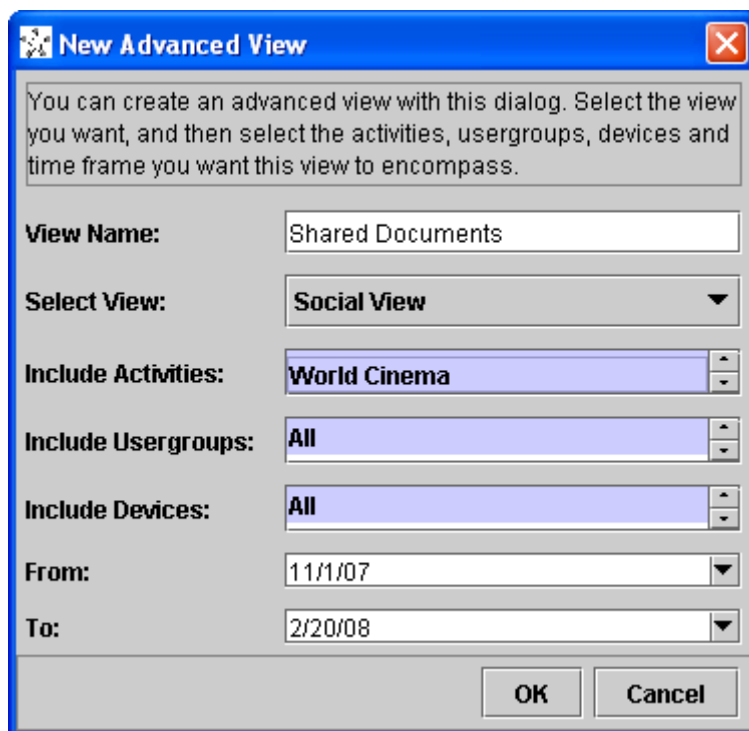


Figure 5-33: New Advanced View application dialog

InfoMesh offers the notion of advanced views to provide further view flexibility. Users can create additional views beyond the simple views associated with each activity, where they can change the activities and context instances incorporated in the view. Using the 'New Advanced View' dialog (Figure 5-33), Aran can specify the type of advanced view (activity, social or map) and select the activities, user groups, devices and time period to incorporate in the view. InfoMesh then generates the view and includes only information items relevant to the selected activities and contexts. The view is saved under the given name, and Aran can open and return to it at any time.

Advanced views allow Aran to view items across various pertinent activities (such as 'World Cinema' and 'Writer's Corner' in the previous scenario, depicted in Figure 5-32), limited to specific people, devices and time frames. As another example, Aran can for instance create an advanced activity view that incorporates his work on all his creative activities, but limit it to only the work he carried out on his tablet PC over the previous month. As he specifically uses his tablet PC for

producing certain artwork, this would help him assess how much artwork he has been producing and how regular his progress and work habits are.

When created for a single activity, advanced views also permit Aran to create more than one activity, map or social view for the same activity. For example, Aran might be exhibiting his artwork at two galleries in his city. He could then create two map views (each one using a different floor layout) for the same underlying items, when planning for the displays.

When an advanced view is open, the ‘View Contexts’ panel switches from simple view mode to advanced view mode (see the ‘View Contexts’ panel for both simple and advanced views in Figure 5-28). In line with the concept of flexible views, the ‘View Contexts’ panel can be used with advanced views to dynamically change the activities or contexts incorporated in the current view, i.e. Aran can add or remove an activity, change the time frame and so on. As with all other InfoMesh views, Aran can apply various display settings to the view, and filter and/or query the view. As such, advanced views empower Aran to create and adapt his view onto his activity or information space to suit his work (for example to satisfy a query or conform to a secondary goal within his work context).

Instead of displaying static information, with advanced views InfoMesh once again allows Aran to dynamically alter his views and relate view content according to various contextual elements that pertain uniquely to him, while providing a rich and visual information context for his work. The end result can be a more natural and personalised interaction experience. In comparison, many systems including hierarchical folders, can often at best offer a static listing of information that is the sum of various relevant content in the information space, without personalisation, versatile contextual elements or dynamic interaction. Furthermore, using these systems, the content is frequently achieved through considerable effort on the part of the user.

5.2.6 SUMMARISING INFOMESH

InfoMesh seen through the various scenarios and activity snaps depicting Aran’s use and interaction illustrate many of the key ideas behind Pervasive Personal Information Spaces by building from the guidelines of the Spaces model:

- Combining the network of personal devices to create an integrated information space with rich information associations.
- Automating information communication, adaptation to device and tracking information usage.
- Providing flexible views on the information space that focus on user activities and contexts such as time, people and locations, with versatile tools for annotating and querying those views.

InfoMesh also highlights many salient features that go hand in hand with Pervasive Personal Information Spaces and flexible views. These include personalising views using natural contextual associations and through various annotations, sharing views or information trails to support social navigation, creating pictorial archives of information, dynamically querying and filtering rich contextual views, and creating advanced views that span multiple activities and contexts.

As a result, InfoMesh pictorially brings together everything that informs user activities on their devices and creates a personal visual diary or ‘story’ of work and progress that is unique to the user. The personal and visual aspects of InfoMesh aid perceiving information, interpreting work, retrieving information using a myriad of contextual cues, and navigating striking and engaging activity spaces rather than moving through non-specific information listings.

Certain implemented facets of InfoMesh though are currently limited due to technology, complexity and therefore also time. As context registration and device restrictions and communication are improved, alongside other technological elements (e.g. accurate tracking of accessed files), InfoMesh would be able to provide flexible views with less user effort and richer detail.

The explored features of Pervasive Personal Information Spaces however prove exciting. They show potential for personalising information-interaction in the ubiquitous computing environment to the natural elements of user activities and contexts, while keeping that information-interaction detailed yet flexible.

5.3 SYSTEM ARCHITECTURE AND IMPLEMENTATION

Behind the scenes, the InfoMesh system was designed and implemented according to the requirements formulated for developing Pervasive Personal Information

Spaces. This section first presents the high-level system architecture, application component and environment specifications for both the desktop/laptop and PDA versions, before describing the design and prototyping process followed for implementing InfoMesh functionality. (Appendix C presents further design details on application object models and classes, as well as InfoMesh operational procedures, information management and communication.)

5.3.1 SYSTEM ARCHITECTURE AND APPLICATION COMPONENTS

The InfoMesh architecture can be seen as comprising several conceptual components. The following diagram (Figure 5-34) presents these and their communication pathways.

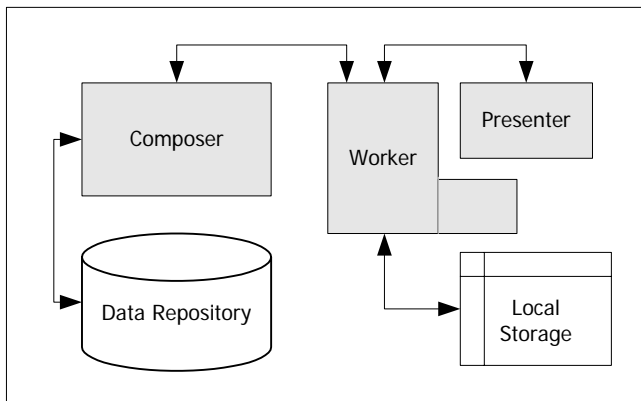


Figure 5-34: InfoMesh application components

The main InfoMesh application components include the *Composer*, the *Worker* and the *Presenter*, bearing some similarity to Burbeck's model-view-controller framework (1992). Each main area of the functional requirements is largely realised by one of these application components. Composer deals with integrating personal information spaces (i.e. managing and manipulating information), the Worker with InfoMesh automation and communication (i.e. functional tasks), and the Presenter with flexible views (i.e. presenting information). Each of the user's devices has tightly interwoven Composer, Worker and Presenter components. Figure 5-35 presents a more detailed view of the system architecture.

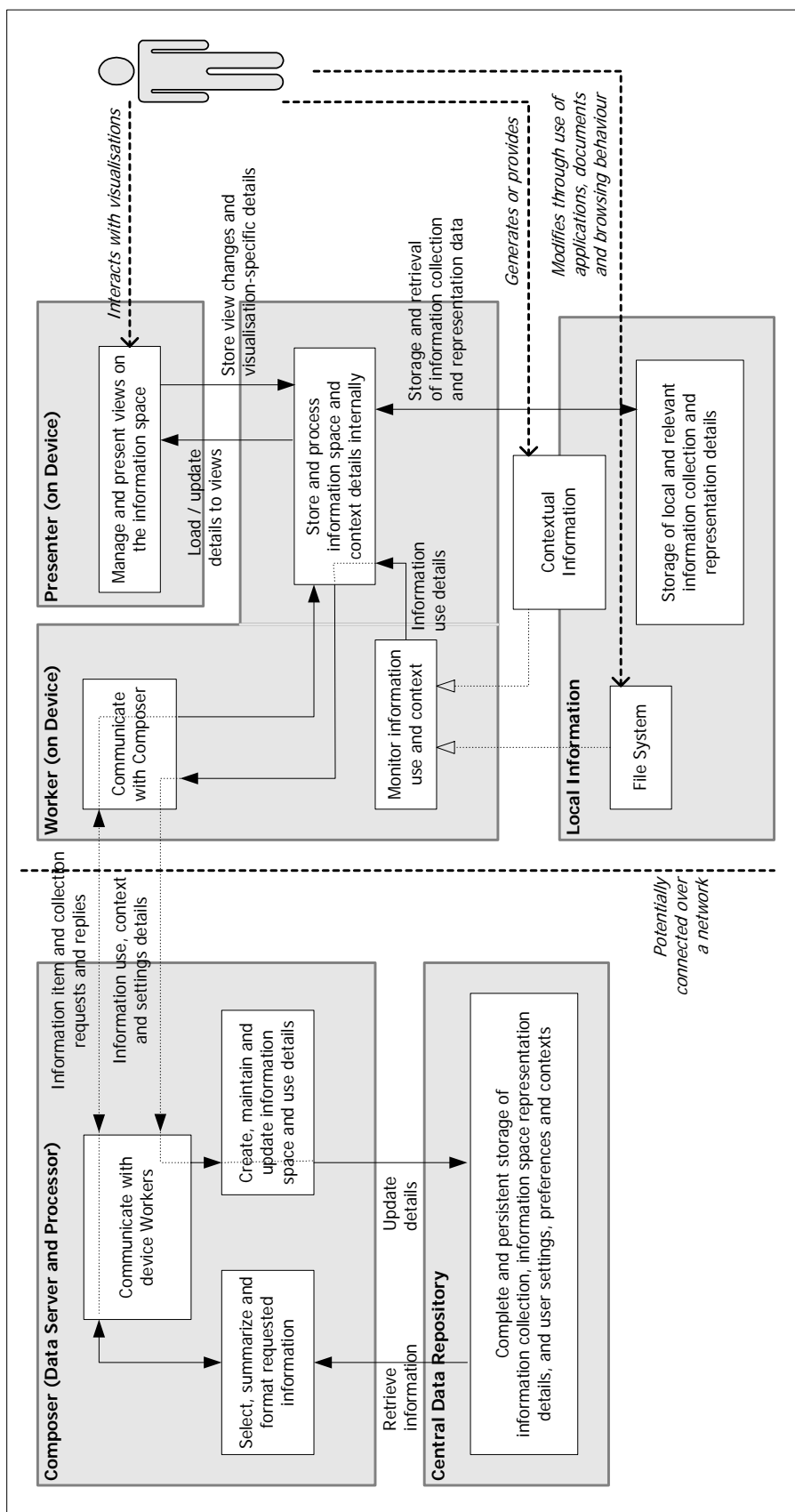


Figure 5-35: InfoMesh system architecture

INFOMESH COMPOSER

The Composer acts as InfoMesh's data server and processor. The Composer integrates and manages the user's entire information space, and provides requested files and details in a suitable form to the user's various devices through the Worker component. The user's entire information collection, high-level information relationships and information space representation details, user information settings and preferences, and privacy and security settings are kept in the *Data Repository*. The information in the Data Repository is updated at each available opportunity.

InfoMesh Composer consists of agents for server-side communication, logical information organisation, and information adaptation to device. The user device with the central information repository runs the full version of the composer component, with the server-side communicator. In secondary devices, the composer component only runs the agent for logical information organisation (which works hand in hand with the session manager agent) for managing a simple local repository of details for update to the central repository.

- The *server-side communicator* shares information with the client (part of the worker component). The agent sends, receives and processes requests and replies with respect to information items and use, context details, and view details. Information is sent as information and view objects.
- The *logical information organiser* structures, integrates and relates all information within the user's information space (including information items, contextual details, annotations, view settings and details) into the central information repository overseen by InfoMesh. With each user device session, this information database is adjusted and updated.
- The *information adapter* formats and adapts the information sent to the worker component according to the receiving device's settings and the user's specifications. For handheld devices, the information adapter currently only sends snapshots of views as on their last use. This can be expanded in the future to instead provide only document summaries, specific documents in entirety or perhaps relevant segments of the information space as requested by the user.

INFOMESH WORKER

The Worker, as the name suggests, takes care of most of the functional tasks on the device. The tasks of the component include monitoring user contexts and information use on the device, managing internal and local storage of information, sending updates of the users' activities and local information collection to the Composer, and finally requesting, receiving and processing details necessary from the Data Repository through the Composer.

The component consists of agents for client-side communication, managing device sessions, a directory watcher and a context monitor. The InfoMesh Worker is active on each device running InfoMesh.

- The *client-side communicator* shares information with the server (on InfoMesh Composer). The agent sends and receives information and view object details encompassing structured information items, contextual details and view details, according to instructions from the session manager.
- The *session manager* oversees user sessions on a personal device and tracks the information to be retrieved from the Composer and the local information to be updated to the Composer, according to user interaction and information use. On secondary devices, the session manager also maintains a small local information structure containing session-related information use and context details for update to the Composer and the repository.
- The *directory watcher* monitors selected folders and web browsing history for file changes signalling user information use, and updates the local InfoMesh information structure with the relevant details (such as which sites were accessed and which files created or modified, when and where they are located).
- The *context monitor* tracks and registers limited details of the user's use contexts, such as details about the user, device, time, and information details, and also incorporates details explicitly specified by the user. These include details about the current device in use, information sources accessed, authors of documents, people that shared information items or that the user sent information to and so on.

INFOMESH PRESENTER

The Presenter has the task of generating and displaying appropriate and flexible views of the information space to the user. The component consists of agents for visual information organisation, and view adaptation and presentation. The InfoMesh Presenter is fully present on each InfoMesh device application.

- The *visual information organiser* selects the segment of the user's information collection for presentation (from the various activities, contexts, views and information objects) from the local information structure, calculates or retrieves view coordinate systems according to the selected view types and structures this information for the view adapter and presenter to manipulate.
- The *view adapter and presenter* takes the selected information from the visual information organiser, filters the information according to further FlexTools settings, adapts the view content to the device capabilities, and presents the view with the applicable content. This agent also updates the current view with all recent information use details as instructed by the session manager, and sends user view manipulation details to the session manager and visual information organiser as required.

(Appendix C details the underlying classes and procedures that capture and carry out the functionality of InfoMesh components.)

5.3.2 SYSTEM ENVIRONMENT

As Pervasive Personal Information Spaces manage information use on several devices, InfoMesh is set up to work with desktops, laptops, PDAs, and in the future can potentially be expanded to work with further devices, such as mobile phones, wearable devices and flexible storage devices. In the current prototype system, InfoMesh supports devices running on Windows XP (for desktops and laptops with network connectivity) and Windows Mobile 5 (for PDAs with synchronisation capability).

The programming tools and environment used to develop the desktop/laptop and PDA versions of InfoMesh are given in Table 5-1 and Table 5-2. For both desktops/laptops and PDAs there are two separate applications, one in Visual C++ and the other in Java that make up InfoMesh.

InfoMesh for desktops and laptops	
Tool	Implementation Function
Visual C++ (Visual Studio .Net 2003)	Monitoring and registering file usage on local device.
Java 1.4.2 (J2SE SDK and Runtime Environment 1.4.2)	Managing the information repository, InfoMesh view content and related tools, interface and interaction, and inter-device communication over a network.
Piccolo 1.1 (based on Java 1.4.2)	Displaying views, with support for navigation and item manipulation.

Table 5-1: Programming tools and environment for desktop/laptop version of InfoMesh

InfoMesh for PDAs	
Tool	Implementation Function
Embedded Visual C++ 4.0	Monitoring and registering file usage on local device.
NSIcom's Crème JVM and Pocket PC emulators	JVM for PDA, based on the J2ME personal profile 1.0 (which includes only some classes and packages from J2SE 1.3.1), and emulators for prototype test runs.
Java 1.3.1 SDK	Java 1.3.1 is used according to the Sun Java Toolkit – J2ME PP 1.1 - for CDC 1.1, for managing the information repository, InfoMesh view content and related tools, interface and interaction, and inter-device communication (which occurs at this point at the time of PDA synchronisation). The AWT package is used to display view content.

Table 5-2: Programming tools and environment for PDA version of InfoMesh

In a given scenario where a user has several personal devices (e.g. a desktop at work, a laptop and a handheld device) as in the case of Aran, the InfoMesh environment can be depicted as in Figure 5-36. The set-up has a central data server and processor, a single complete information repository, local device-based information repositories, and device-based client applications. The user's devices communicate and share information through InfoMesh's data server and repository. The server and repository is used to manage, store and process the individual's integrated information space.

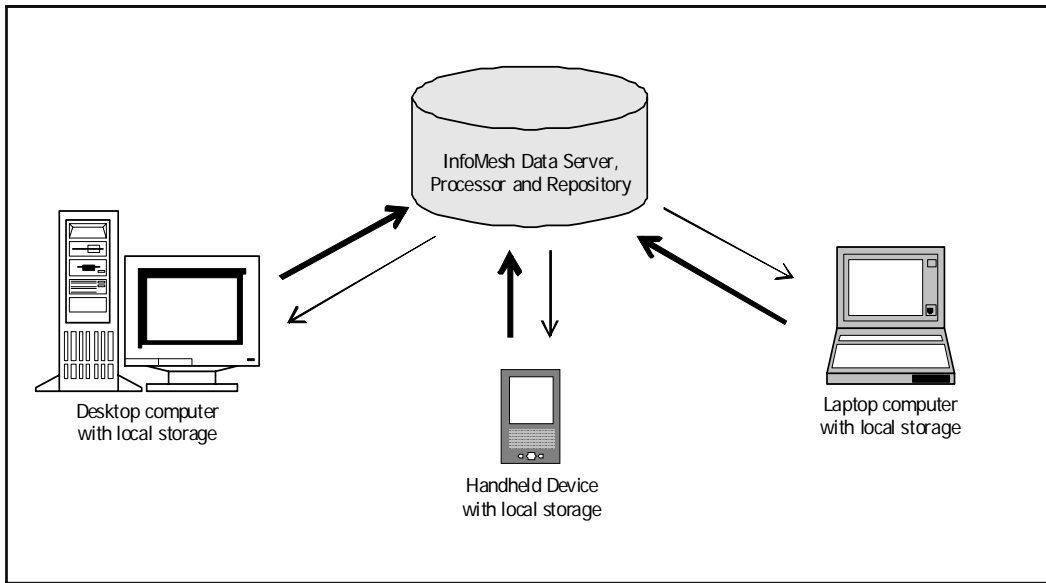


Figure 5-36: InfoMesh set-up

View content, information items and supporting details pass from the data server and repository to the individual's devices, according to the current context, settings and device limitations (thin arrow). Registered contextual details, details of new activities, created files and altered settings pass from the individual's devices to the data server and repository (thick arrow).

In the present research prototype, the InfoMesh data server and repository is placed on the user's main or default device and incorporated into the device's InfoMesh application. InfoMesh installed on secondary devices behaves as a smaller multi-purpose client with corresponding features switched on and unnecessary functionality disabled, until perhaps the user decides to change the device's status from secondary to default. The InfoMesh PDA version is basic and separate, and does not carry any of the extra functionality to support a default device status.

5.3.3 THE DEVELOPMENT PROCESS

The process for designing and implementing InfoMesh functionality was iterative, similar to the process of designing the InfoMesh interface and interaction. The process utilised a top-down methodology for structuring InfoMesh development, an object-oriented method for modelling and designing the information and system architecture, and an adaptive and evolutionary prototyping technique for developing the InfoMesh system. Where possible, InfoMesh was designed with

the aim of building in some extensibility to support further contextual views and devices like mobile phones.

Within the ubiquitous computing scene, there are multiple platforms to consider and device constraints regarding network communication and the types and amount of information collected, presented and stored. Consequently, the design and prototyping process included decisions on the environment that would best lend itself to developing InfoMesh, the appropriate system architecture for deploying InfoMesh on several devices, as well as the best way to structure, communicate and store the web of inter-related information.

The research scope and complexity for developing Pervasive Personal Information Spaces was considered necessary to test and evaluate the research ideas as best as possible. However, the same expansive scope and complexity necessitated work in several subject areas and required various supporting activities, and so introduced numerous issues and problems into the design and prototyping phase. These include limitations of selected programming environments, time constraints, structuring and re-structuring large quantities of information, integrating components, and implementing and testing InfoMesh's spread-out and networked functionality.

The coming sections summarise the system design, prototyping and testing activities in this research phase, highlighting the issues that arose and tracking the encountered difficulties, as well as indicating the final solutions and outcomes.

DESIGNING INFOMESH

Designing InfoMesh functionality focused on three areas, namely a) the system architecture and application components, b) the application classes and package hierarchy, and c) the application information and communication design.

Essentially a top-down design methodology was followed to understand InfoMesh functionality and structure it for easier implementation, which consisted of the following steps:

1. Constructing the system as several application components, where each focuses on tasks relating to functionality support, information presentation or information management.
2. Delegating tasks or services within each of the components to specific agents.

3. Using object-oriented modelling and design to create a specific object model and corresponding package for each component, consisting of a set of classes that work together.
4. Developing a single or group of inter-related classes within the package for performing the tasks and services of each agent.
5. Developing the procedural design, application information design and storage, and communication and operational protocols, by working from the task and service descriptions of the agents.

InfoMesh functionality as described by the requirements spans several broad areas, and so it was decided to consider and design InfoMesh as several interacting application components, each with its own area of responsibility. The division into specific application components mirrors the requirement categories conceptually, separating functional tasks from tasks relating to presentation, and tasks relating to managing and manipulating information. Within each component, tasks were delegated to specific agents. It was clear that these divisions into components and agents may not map onto the implemented components directly, however, they would provide a valuable framework for conceiving and prototyping InfoMesh functionality. The application component and agent divisions were fleshed out with further detail several times during the prototyping process.

The next step was to develop an object model for each application component, with specific classes or groups of classes directed towards performing the services or tasks of specific agents. Designing and creating the InfoMesh information structure could not be done in one go, due to the functional complexity and large amount of information stored and manipulated in InfoMesh. The InfoMesh structure was defined, built, organised and re-organised over numerous iterations during the design and prototyping process, to create a functional related model of information. This information had two important elements, information stored about information items created and used by the user and information used for storing and generating views. The former required information structures that supported multiple multi-directional relationships that could overlap and be combined for views. The latter required re-structuring several times to predominantly support multiple views (each with separate co-ordinate spaces for the same underlying items that supported swapping views and changing

underlying contexts), as well as secondary elements like FlexTools settings (for tracking filter and query options for each view and advanced view contexts) and so on.

The final step in designing the InfoMesh system was to flesh out the task design for agent services, design application information through class interfaces, as well as develop the protocols and procedures for inter and intra-device communication, data monitoring and collection, data persistence and system operation. Some of the concerns in this step included structuring information for easy persistent storage and transfer, deciding how and what information would be registered in tracking user activities, and developing ordered operational procedures for running InfoMesh and managing device interaction.

PROTOTYPING INFOMESH

The prototyping process for InfoMesh was slow, as it was at times problematic. The process led to the development of several separate prototypes in trying out different programming tools and environments. The program versions had variations in their components, information structure and protocols according to how well the programming tools and environment could support and accommodate the underlying design. Once the final programming environment was selected, a couple of prototype versions were developed for the different target devices.

As InfoMesh functionality was expansive, requirements were implemented step-by-step and iteratively alongside one another, with some requirements curtailed due to feasibility and time constraints (e.g. view options for changing visualisation styles and data encryption for inter-device communication). The functional elements were revisited numerous times for updates, testing and integration. The main approach was to develop the information structure first, followed by a foundation for creating the view interfaces, registration of file usage, application communication and networking, and finally the individual views themselves. InfoMesh was developed for desktops and laptops first, making use of various activity snaps and corresponding test tasks to refine the underlying features and functionality. These activity snaps and test tasks also aided in highlighting issues and generating further ideas for future consideration. InfoMesh was subsequently adapted for PDAs. After several trials, it was clear that an implementation of

InfoMesh for PDAs had to be simplified considerably due to numerous restrictions in the programming tools.

Prototype 1: Prototyping using GapiDraw and Visual Studio

Initially the programming environment selected for implementing InfoMesh included GapiDraw (a graphics SDK from www.gapidraw.com), Visual Studio .Net 2003 and Windows CE tools for programming using Visual C++ and MFC classes, and OpenTrek (a peer to peer networking platform from www.develant.com/opentrek.php).

GapiDraw was used to create the visual view content for InfoMesh, while Visual C++ was used to develop the behind-the-scenes functionality. GapiDraw was selected as it would work on multiple platforms, with OpenTrek managing the network communications. Visual Studio would support easy access to the underlying Windows API for monitoring and registering file usage, a necessary requirement for InfoMesh. These prototyping environments however brought up numerous issues and problems, which severely hindered and slowed prototype development over the months the tools were used. Prototyping was only attempted for desktops and laptops using these tools.

GapiDraw, as a low-level graphics toolkit, proved difficult to integrate into Visual C++ for InfoMesh requirements, and very slow for setting up the foundation for InfoMesh view development. Consequently, it became obvious that the high-level requirements for creating rich, object-oriented views would not be met within an acceptable time-frame, if at all, using GapiDraw.

Visual C++ using MFC classes was fine for implementing functional tasks such as monitoring directories and registering file use, however in supporting the flexible InfoMesh interface and information structure, the environment proved too convoluted and problem-ridden for creating solutions for implementing the system requirements. Example issues ranged from difficulties in implementing proper file transfer between applications and creating thumbnails of files used by the user, to creating GapiDraw integrated Visual C++ views that were object-centric and detailed in their interaction. Implementing each requirement usually took substantial effort due to problems that required work-arounds and alternative solutions, and soon it became obvious that the selected tools were inadequate and inflexible for developing InfoMesh efficiently.

Prototype 2: Desktop and laptop prototyping using Java and Piccolo

InfoMesh prototyping was then migrated to the Java programming environment, making use of Piccolo for Java, a 2D structured graphics framework from www.cs.umd.edu/hcil/piccolo/ (see Bederson *et al.* 2004). Piccolo, a high-level programming tool, was selected since it would allow for object-centric view development from the start. Java seemed appropriate for InfoMesh development, as it would support multiple platforms with minimal adaptation.

Most of the previous prototype could not be re-used, except for the Visual C++ component that monitored and registered file usage. This component was adapted to work as part of the new prototype. Some of the programming logic used in structuring application information in the previous prototype was also useful to build on.

There were still some problems and issues with these tools, such as those relating to tracking and presenting web browsing activity, and transferring large subsections of the user's information space between applications and across the network. Certain limitations of not only the tools in use, but also the current state of technology affected the prototyping. However, programming in Java using Piccolo was far more feasible and successful than programming using GapiDraw and Visual C++.

Prototype 3: PDA prototyping using Java

Once the desktop and laptop version of InfoMesh was half underway, prototyping the PDA version was considered using Java and Piccolo. First the Visual C++ component for monitoring and registering file usage was migrated to the Windows CE environment for working on the PDA. Beyond adapting the component, there were several adjustments to be made, as certain functionality was not supported in the CE environment.

The next step was to consider the Java and Piccolo set-up for programming the PDA version of InfoMesh, which involved various options and programming trials to develop a solution. In summary, the important options and prototyping processes included the following:

1. Developing the Windows CE C++ 4.0 version by trimming and adapting the Visual C++ component for monitoring and registering file usage. There were limitations to contend with, as WinCE .Net SDK did not support some of the

- necessary functionality offered in Visual Studio.Net framework for monitoring file changes. As a result, several alternative solutions needed to be worked out.
2. Selecting a JVM for use with PDAs (specifically for Pocket PC 2003 and later on for Windows Mobile 5). Only a few practical JVM options were available for running Java applications on PDAs: NSIcom's Crème, IBM's J9 and the MySaifu JVM. All three were tested out, but even though all of them had mild to serious shortcomings, the final decision was to go with NSIcom's Crème.
 3. Carrying out programming trials for incorporating Piccolo classes in the InfoMesh PDA program version, by using SWT, AWT and Swing classes at different times, using different JVMs integrated with various additional libraries. An important issue here is that the many of the JVMs are based on Java 1.3.1 or older, whereas the InfoMesh desktop applications use Java 1.4.2, which Piccolo was set up for.

This last process involved trying out various programming solutions and testing them out on a Pocket PC emulator. Initially the use of Swing classes (used in the desktop version of InfoMesh) was avoided, as Swing was unsupported by several JVMs and not advisable for PDAs as the applications would run very slowly. Piccolo was directly supported through Swing or SWT. So first, Java SWT classes were used in programming to allow the use of Piccolo classes. Certain SWT classes were not supported though in the J2ME personal profile 1.0 or 1.1 and therefore J9 and Crème for example. Then it was attempted to convert the Piccolo Swing canvas classes into AWT based ones. However, the original Piccolo classes were dependent on non-widget Swing classes as well, which resulted in other functionality issues that could not be solved.

The JVM used was switched between J9, NSIcom's Crème and MySaifu JVM and back in an attempt to revert to using Swing to circumvent these issues (Crème supports a basic Swing library, and a Swing library was incorporated into J9). Even still, using the SWT or Swing class options at this point came up with irresolvable errors for using Piccolo classes.

In between, the PDA OS in use was also changed from Pocket PC 2003 to Windows Mobile 5, by employing a newer device with increased display resolution and abilities (such as supporting landscape and portrait screen orientation, and wireless connectivity).

The long journey of carrying out the PDA programming trials resulted in a decision to forgo the use of Piccolo and interactive views on PDAs that appropriately mirrored their desktop counterparts. In the remaining time-frame, InfoMesh for PDAs was simplified to tracking and updating information usage, communicating with the central information repository for uploads and downloads, while only presenting images of the various views as they were on their last update on a desktop or laptop. The Java AWT package served to develop the basic view presentations.

EVALUATING AND TESTING INFOMESH DESIGNS AND PROTOTYPES

The InfoMesh architectural design and early prototype versions underwent simple non-user based evaluation and testing throughout the design and prototyping process.

Simple structural and functional (white box and black box) tests were conducted on segments of InfoMesh, in isolation or combination. Structural tests were done intermittently using random mock data, predominantly to test prototype classes, components and procedures as they were written and integrated.

Simple controlled functional tests were done at a few specific intervals using activity snaps and specific test tasks that matched the activity snaps and underlying persona. As the activity snaps simulated real world user activity and comprised of a web of related information, they proved insightful and engaging when testing InfoMesh. The functional tests were mainly used to refine the architectural design, check how well the design and functionality matched the requirements, and improve the interface and interaction design. They however also aided in identifying programming and procedural errors.

Various design and functionality issues needed testing at both higher and lower programming levels. These included component functionality, component integration, InfoMesh version functionality, inter-device communication and its timeliness, transfer of information objects between devices, data collection and persistence of both file usage and web browsing activities, information structuring, information presentation on various views and so on.

The various tests carried out did not include long-term use (i.e. beyond several days of use), due to the incremental changes and updates to InfoMesh. All these tests did reveal specific performance issues in InfoMesh. As a prototype system,

though some problems were corrected, some of these issues were not a priority and were not ameliorated in the implementation time frame. Some of the issues included:

- longer synchronisation times between extended device sessions due to the transfer of a large amount of document content,
- problems with incorrect file information when single-device-only sessions were not adhered to or InfoMesh was not switched on for a session,
- problematic tracking of web history, where for example various web page elements like advertising banners were also automatically tracked at times and pages with many elements infrequently created issues in multi-threading object synchronisation, and
- longer generation times for advanced views and switching contexts for those advanced views.

Some of these issues (such as the second and fourth listed above) could create run-time problems during long-term use of the current prototype system.

5.4 SUMMARY

InfoMesh brings together the information individuals access on their different personal devices, to provide anytime-anywhere-any context access to information through any of these devices. From the user's perspective, InfoMesh provides a variety of versatile, contextual views for carrying out work, and for relating and interpreting their documents, work and use context. This chapter looked at how users could use, interact with and understand these views and the tools to manipulate them, by considering worked-out scenarios and activity snaps depicting InfoMesh use for the persona 'Aran'.

InfoMesh is a multi-device prototype system that is built on the characteristics of the Spaces model, and consequently illustrates key facets of the Pervasive Personal Information Spaces concept. Consequently, InfoMesh serves as an illustrative example for understanding, investigating and evaluating those facets, which aim to provide ubiquitous access to personal information by integrating and relating distributed information, automating information communication and usage tracking, and providing rich and personalised context-based flexible views.

The InfoMesh prototype has been iteratively designed and built from the formulated requirements and detailed interface and interaction designs discussed in the previous two chapters. The system is made up of several application components working together, namely a Composer component to manage the information repository, a Worker component to perform the behind-the-scenes functionality of registering and communicating information, and a Presenter component to visually adapt and present users with views on the information space. Having worked with several prototyping environments, the final InfoMesh versions for desktops/laptops and PDAs were developed using Visual C++, Java and Piccolo.

During the early design and prototyping process, evaluation largely rested on testing the design and early prototypes in non-user based evaluations, frequently making use of activity snaps and test task scenarios. The next two chapters now report on the user studies conducted on InfoMesh at several key points in the prototyping cycle. These studies informed further InfoMesh development and helped evaluate the underlying research concepts.

CHAPTER 6: EVALUATION I

STUDYING INFOMESH VISUALISATIONS

6.1 INTRODUCTION

The InfoMesh prototype system illustrates the idea of Pervasive Personal Information Spaces by implementing features identified through the Spaces model. In association, these features aim to improve ubiquitous access to distributed personal information spaces. InfoMesh development benefited from the use of various analytical, structural and functional evaluation techniques. This and the next chapter focus on user-based evaluation of InfoMesh.

InfoMesh user evaluation was carried out in several phases at different stages of InfoMesh development. This chapter first provides a brief background to user evaluation in this research work, with details on the evaluation approach taken. Subsequently, the chapter reports on the first phase of user evaluation carried out to evaluate and assess InfoMesh visualisations for further InfoMesh development, and thereby to also evaluate various aspects of the Spaces model and consequently Pervasive Personal Information Spaces.

The first phase of InfoMesh evaluation involved a user study on its visualisations through interface designs and an early prototype displaying activities corresponding to the persona 'Lisa'. Study findings showed user support for many of the InfoMesh visualisations and view elements, as well as the underlying research concepts for improving contextual access to personal information. The study also highlighted ways to refine and target further InfoMesh development for the next phase of evaluation.

6.2 BACKGROUND AND EVALUATION APPROACH

InfoMesh presents a multi-faceted, interactive prototype with a complex underlying functionality. The prototype system was built on the strengths of various frameworks and new engaging concepts, and informed by a review of related research and developments, a detailed conceptualisation, requirements analysis, and an extensive design process. In line with user experience design and user-centred design methodologies, users were involved at key points during this development process, in order to inform and guide the development of InfoMesh.

Focus group interviews: Early interviews helped understand individuals' daily information-interaction and ubiquitous use of personal computing devices, and

their attitudes on the concept and utility of Pervasive Personal Information Spaces. The focus group interviews along with informal discussions also formed a basis for generating personas and activity scenarios, and helped refine the requirements for developing Pervasive Personal Information Spaces. (See Appendix A for details on the focus group study and a summary of the findings.)

User study on InfoMesh visualisations: Once InfoMesh desktop and PDA designs were completed and an early InfoMesh prototype was developed, a study was conducted to assess various InfoMesh interface designs and views, view elements, and user perspectives and preferences on the same. The study findings helped refine and direct further development, so that more specific and distinguishing aspects of Pervasive Personal Information Spaces could be targeted in InfoMesh for evaluation in the next study.

User study on InfoMesh visualisation, interaction and use: Users evaluated a more thorough implementation of InfoMesh in a second study. The study emphasised select InfoMesh views and also the tools to manipulate them through various exploratory, assessment and comparison tasks. Here, the findings helped fine-tune InfoMesh, shedding light on user perspectives on InfoMesh views, the interaction supported by the views, as well as the use and usefulness of the system.

Investigating InfoMesh long-term use: Finally, an early reflection on the long-term use of InfoMesh underscored previous findings and helped lay the foundation for a future longitudinal study of InfoMesh. The investigation also uncovered the necessary adjustments required to support such a broad study.

The crux of user evaluation in this research has revolved around investigating InfoMesh view designs and prototypes through tailored user studies, in order to test the research hypothesis. The hypothesis postulates that “*context-based flexible views provide better contextual, ubiquitous access and visualisation of information than current single-device metaphors*”. The approach to the user evaluation considered and employed various methods, techniques and ideas, to target different aspects of InfoMesh. At the same time, several ideas helped form the groundwork for further studies (focused and long-term) of InfoMesh and other similar implementations of Pervasive Personal Information Spaces. These ideas

would support investigations into InfoMesh and Pervasive Information Spaces from several different angles.

Broadly, the study objectives emphasise the following elements to test the research hypothesis:

- User understanding of concepts introduced by InfoMesh.
- User understanding and interpretation of InfoMesh desktop and PDA visualisations.
- User interaction with InfoMesh (including FlexViews and FlexTools).
- User comparison of InfoMesh views with hierarchical views displaying the same information.
- Usability issues in the InfoMesh designs and prototypes.
- User perspectives on Pervasive Personal Information Spaces and their use as exemplified by InfoMesh, in providing ubiquitous access to information by supporting high-level activities and their work context.
- User preferences, experience and information behaviour with respect to their everyday computing as well as their interaction with InfoMesh in the studies.
- Preliminary understanding of long-term use of InfoMesh for supporting user activities and information interaction.

The evaluation methodology employed to accomplish these objectives centred on multiple small, successive and intensifying user studies (see Nielsen, 2000), where early studies have a narrower scope and each study emphasises additional specific conceptual, functional and interactive elements. Nielsen (2000) advocates running multiple smaller studies (with no more than 5 users) for the best results. With iterative design, each study can then help improve system design rather than just uncover weaknesses, and support further evaluation. The two main user studies in this research employed 6 participants each, with study sessions running between 2 to 2.5 hours each. The goal was to get detailed views from participants for supporting further work on InfoMesh and Pervasive Personal Information Spaces. These views could only be detailed and meaningful through an in-depth exposition and interaction with InfoMesh. As such the findings may be less generalisable. However, shorter sessions and a larger number of participants would only provide more superficial and less accurate view points, as Pervasive

Personal Information Spaces spans multiple concepts illustrated through multiple system aspects. The studies were planned for key points in the design and prototyping process, with the first two studies carried out in a usability lab environment and the preliminary longitudinal investigation in the real world.

The user studies incorporate a variety of learning, exploratory, assessment and comparative tasks. They make use of prototype video demonstrations, user guides and background material, view designs that make up chauffeured prototypes, and working prototypes of different levels of functionality. All of these elements, along with the tasks and questionnaires, focus on specific personas, and related scenarios and activity snaps. In the studies, these personas and activity snaps formed a powerful point of reference in interacting with InfoMesh. The personas and activity snaps helped direct participant attention to view elements and content, their realistic use and therefore their interpretation, appropriateness and usefulness. They also helped draw out personal preferences, conceptual issues and usability issues. This was largely due to the fact that activity snaps did not present disparate pieces of information, but an annotated activity trail that had meaning and could be interpreted and used to make inferences about the corresponding persona's work.

The studies predominantly made use of various observational and query techniques (as described in Dix *et al.*, 1998), specifically as the goal was to expose user impressions, perspectives and experience of Pervasive Personal Information Spaces. As such, the emphasis lay on qualitative rather than quantitative data.

Observational techniques were used to note down user interaction, and were used with co-operative evaluation for early study segments and the 'think-aloud' method to get insight into participant preferences and interaction behaviour.

Query techniques used in the studies involved a variety of questionnaires (e.g. background, post-task, experience sampling, end of study), non-directive probes to encourage discussions, facilitative questions to get user views and suggestions, and projective techniques. Projective techniques (see Silverman, 2000) can help capture user impressions, ideas and expectations. In the studies, projective techniques encouraged participants to explain and flesh out concept descriptions they had read, interpret prototype demos and views from the persona's point of

view, and complete sentences about the prototype systems and underlying concepts.

Experimental techniques of interest chiefly pertained to long-term evaluation, and were designed to capture and analyse data on feature use frequency, timeliness of InfoMesh processes (e.g. information uploading, view generation, inter-device communication), hours of interaction, and generated views and view content information.

The studies were also planned out to take advantage of both user objective and user subjective evaluation, whereby the latter incorporates participant-specific activity snaps into the prototype for evaluation. User subjective in this case means tasks uniquely oriented or targeted towards the participant. This style of user subjective evaluation helps bridge user studies carried out in the lab environment with user studies in the environment of real world use, by gaining insight into a participant's interaction choices and information usage based on his or her own activity data. Using participant activity data would provide more insight than using another person or persona's activity data, or of course dummy data or no data at all.

Due to time constraints, the user subjective evaluation tasks were curtailed in the user studies. The second study touched upon the technique in limited fashion by discussing participants' recent activities and revisiting them throughout the study when discussing their perspectives on InfoMesh and its use. The blueprint for applying user subjective evaluation with the use of user-specific activity snaps (described in section 4.3.2), however, promises to be of use in future studies.

A longitudinal field study would shed light on the personalised interaction experience offered by InfoMesh through daily ubiquitous use. The nature of InfoMesh interaction and use provided an opportunity to investigate and plan out several remote evaluation methods (Castillo, 2002) for studying long-term use, including the Experience Sampling Method (Consolvo and Walker, 2003), which was looked at in section 2.4.3. InfoMesh had a final component built in to query users (e.g. through interval-based experience sampling questionnaires), and log and collect interaction details for the study (e.g. action history, activity views and information trails, and view screenshots). The scope of the research and several material issues limited the evaluation to a preliminary investigation. The

investigation reviewed InfoMesh use, InfoMesh robustness and the study plan in preparation for a future field study.

6.3 STUDY ON INFOMESH VISUALISATIONS

The study on InfoMesh visualisations focuses on the design, content and appropriateness of the system's various desktop and PDA visualisations. The study encourages participants to explore the visualisations with the help of several activity snaps (corresponding to the persona 'Lisa') to assess how well users understand and interact with the contextual visualisations built on the Spaces model. The study also focuses on how participants compare the visualisations with current hierarchical folder views of electronic information, especially in view of high-level user activities and user work habits.

The following sections first detail the purpose and problem statements for the study, and the study method summarising the study participants, tasks, environment, procedures, data collection and evaluation measures. The findings from the study are then analysed and discussed in depth, in view of their impact on further InfoMesh development and the second stage of InfoMesh evaluation.

6.3.1 PURPOSE AND PROBLEM STATEMENTS

The purpose of this first study was to evaluate the InfoMesh visualisations provided by the desktop prototype and PDA paper designs on a conceptual and practical level. The prototype views and designs investigated include the overview, activity view, map view, social view, work view, universe view, all activities and views, and the notice board, as well as alternative designs for some of the views. The goal was to use the observations and insights from the study towards selecting and refining the view designs and interaction, assessing the usefulness and suitability of the conceptual model underlying the prototypes and adapting the same as necessary, before a second study was conducted on InfoMesh use. The study was designed to answer the following questions:

- What kind of device interaction and information behaviour do users carry out within the ubiquitous computing environment?
- How well and easily can users understand the concepts introduced by InfoMesh? (*This includes the concepts of integrated information spaces,*

activity and context-based visualisations, flexible and adaptable annotated views, and automated monitoring of information use. The FlexTools feature is not explored in detail in this study.)

- How well and easily can users understand the visualisations presented by InfoMesh? (*This includes understanding the activities and contexts represented in the visualisations, the tools to manipulate and annotate the views, as well as the relationship between the desktop and PDA visualisations and information items.*)
- What are some of the usability issues in the current InfoMesh visualisations?
- How do InfoMesh views on information compare to current hierarchical folder views?
- What are user views on ‘Pervasive Personal Information Spaces’ (as exemplified by InfoMesh) and their use, especially in providing access to their electronic information and supporting high-level activities?

The study tasks largely tackle these questions in order. Consequently, the study analysis and discussion follow the same sequence in answering them.

With this focus, the study on InfoMesh Visualisations goes some way towards testing the research hypothesis: *context-based flexible views provide better contextual, ubiquitous access and visualisation of information than current single-device metaphors.*

6.3.2 METHOD

In this study, participants were introduced to InfoMesh and asked to consider the desktop and PDA visualisations the system provided. They read through concept descriptions and activity scenarios for the persona ‘Lisa’, which formed the basis for their reflections on the InfoMesh visualisations. Throughout the study they were encouraged to ask questions and discuss their views, to help in providing insight into the appropriateness and usefulness of the visualisations.

A pilot study was conducted several days before the user studies were carried out, to assess and fine-tune the user study material (including the tasks, InfoMesh material, participant workbook and evaluator guide), and also to check the time taken for the tasks.

PARTICIPANTS

Six participants took part in this study, which was conducted at the Usability Laboratory in the Department of Computer Science at the University of Waikato.

Each participant was assigned to a separate session, with each session running for approximately two hours. The participants were all graduate students in the department.

Corresponding with the target population for the InfoMesh system, the chosen participants were computer users with a reasonable to high level of computer skills with relation to authoring and gathering documents, managing large amounts of electronic information, and using multiple personal computing devices (such as desktops, laptops and PDAs).

TASKS

The study had five main segments, consisting of readings, discussions, exploratory or comparative tasks, and questionnaires. Throughout the study, the participants were able to voice any thoughts relating to the tasks and discuss their viewpoints.

Segment 1 primarily focused on a background questionnaire for obtaining information on the participant's information management practices using multiple devices.

Segment 2 provided participants with an introduction to the InfoMesh prototype and visualisations. Participants read through a concept description and watched a video demonstration of the early InfoMesh prototype. They then answered a second questionnaire by expressing their impressions of the ideas behind Pervasive Personal Information Spaces and the InfoMesh interface.

In segment 3, participants explored a series of InfoMesh visualisations (various prototype visualisations and paper designs). They first read through a description of the persona 'Lisa' and her use of InfoMesh, before considering the prototype and paper desktop visualisations that matched the given scenarios. Participants subsequently looked at the related paper PDA visualisations, before answering a third questionnaire, which asked about their views and reactions, and their understanding and interpretations of the different visualisations.

Segment 4 presented the participants with a comparative task in which they compared hierarchical folder representations of information with InfoMesh visualisations of the same information.

Finally, in segment 5, participants answered a final questionnaire about their views on the strengths and weaknesses, and use of InfoMesh visualisations.

USER STUDY ENVIRONMENT AND EQUIPMENT

Potential users would primarily make use of the InfoMesh system on their personal desktop computers at home, office or similar environment, or on the go when using InfoMesh on their PDAs and laptops. A usability lab was selected to evaluate InfoMesh visualisations in this first study, as it suitably recreated the first fixed location example for assessing initial user views.

The study was partially conducted on a personal computer running Windows XP, which ran the InfoMesh desktop prototype. Both the *Composer* and *Presenter* applications that make up the InfoMesh system, their supporting programming environments, and application data were installed on the computer. The device also provided the user with access to the Internet using Internet Explorer 6 or above. A Dell Axim X5 PDA was also available and used as an example device that the PDA designs would be implemented for.

Further physical artefacts and support material used in the user study included audio recording gear, physical PDA interface designs, an evaluation interaction guide, an observation guide, and a participant work book containing task cards, a research description, persona description and activity scenarios, and several questionnaires.

PROCEDURES

Each study session followed a simple procedure that consisted of several steps. Participants were first greeted and introduced to the study and study environment. They were asked to read a consent form and the bill of the rights. The evaluator explained the purpose of the study, the type of tasks they would carry out and mentioned that an audio recording would be made of the study session.

Once participants consented to the study, they were given a workbook with the study material and were asked to answer the background questionnaire. The evaluator then provided the participants with a brief introduction to the devices

and designs that would be used in the study. This step included a video demonstration of InfoMesh. Participants were then invited to work through several exploratory tasks using the InfoMesh desktop prototype and PDA paper designs. These tasks were interspersed with readings, questionnaires and discussions. The tasks served to reveal participant understanding and views on Pervasive Personal Information Spaces presented by the InfoMesh desktop prototype and PDA designs.

At the end of the study, participants were asked to answer a final questionnaire and discuss their views of the InfoMesh visualisations and study tasks. They were then thanked for taking part in the study and rewarded for their time.

The evaluator/observer was present with each participant for the duration of the study session, and performed several tasks with the use of an observation and interaction guide. These tasks included:

- Explaining all the study tasks to the participants, and encouraging them to freely give their comments, share their ideas and ask questions.
- Recording comments, ideas, and answers to questions; timing tasks; manipulating the PDA paper prototype to match user interaction; and setting up the InfoMesh visualisations and folder views as appropriate for the tasks.
- Playing a collaborative role in the exploratory tasks, and participating in the task and questionnaire discussions.

DATA COLLECTION AND EVALUATION MEASURES

To evaluate the InfoMesh visualisations and the underlying concept model, the following largely qualitative data was gathered and clarified:

- Details on participant understanding of the conceptual model underlying the InfoMesh prototype and designs.
- Details of how participants explored and interpreted the visualisations provided by the desktop prototype interface and PDA designs.
- Details on participant interaction with the desktop prototype and PDA designs.
- All difficulties, misconceptions and errors encountered by the participants during the study. (These would be classified, and the possible sources of these problems would also be determined and noted.)

- Commentary on how participants compared views of electronic information as provided by InfoMesh visualisations and those provided by current hierarchical folder views.
- Participant views on Pervasive Personal Information Spaces and its use, especially in providing access to information and supporting high-level activities.

The data was collected and compiled in several ways in the user study. Firstly, the evaluator recorded (through observation comment sheets as well as an audio recording) participant comments, views, questions and discussions with the evaluator. Secondly, the evaluator recorded the observations of how the participants completed the tasks and how they used and interacted with the prototypes. Finally, data was also gathered through the four questionnaires that the participants answered at various stages during each study session.

6.3.3 STUDY ANALYSIS AND DISCUSSION

The observations and views gathered from the first user study on InfoMesh shed light on several aspects of the InfoMesh visualisations:

- The background questionnaire provided insight into participant information management practices using multiple devices, which has a bearing on how different users would potentially view and make use of InfoMesh features, specifically the various visualisations and visualisation content.
- The concept and InfoMesh introduction helped gauge user perceptions of the Pervasive Personal Information Spaces concept and their first impressions of the InfoMesh interface.
- Exploratory tasks with the InfoMesh desktop and PDA visualisations (displaying activity snaps of Lisa's work) allowed participants to share their reactions, thoughts, ease of understanding and interpretation of the various visualisations, their content, appropriateness and use. These tasks also brought various interaction and usability issues to the surface.
- Comparing InfoMesh views and hierarchical folders views of the same information helped determine user perspectives on their use and usefulness, similarity and complementary features.

- The end of study questionnaire and discussions gleaned user views on Pervasive Personal Information Spaces, the strengths and weaknesses of InfoMesh, and the application's use in the real world.

BACKGROUND QUESTIONNAIRE

Question: What kind of device interaction and information behaviour do users carry out within the ubiquitous computing environment?

The background questionnaire focused on questions about participant information-interaction in the ubiquitous computing scene, especially with respect to user devices and activities, information organisation and synchronisation, information relationships and work context, and tracking and annotating work.

Device use and access

All participants in the study accessed and used several computing devices on a regular day-to-day basis, and occasionally accessed devices at libraries, Internet cafés and friends' houses. (Though all users had a mobile phone and used other devices such as storage devices, digital cameras and music players, these were not considered in-depth in the background questionnaire.)

About half of the participants used one laptop for work at home and while travelling, and a desktop at university. The rest had at least one extra desktop and/or an extra laptop that they used alongside these devices.

Nearly all participants used their desktops and laptops regularly. Several participants also had PDAs, but used these less frequently. The activities these devices were used for varied significantly between participants. For example, one participant used her laptop largely for watching movies, graphics, web browsing and instant messaging; used her lab computer for university work; and used her home desktop computer for programming, backing up information, music, video and gaming. Another participant used her university desktop largely for her research programming, while using her home laptop for web browsing, photos, university work, presentations and articles, music, web design and shopping.

The questionnaire highlighted that though more than one device was used for certain activities (such as research work and web browsing), participants also had several activities that were solely carried out on a specific device (e.g. video gaming or online shopping).

Information organisation and synchronisation

The documents users actively synchronise are important to understanding how and what information is shared between user devices. Participants in the study synchronised information to both provide access to important working documents on different devices and to back up information for safety and archival purposes.

Information was synchronised across university or home networks, through email, using a USB storage device, or using a synchronisation protocol as with PDAs. None of the participants in the study made use of separate synchronisation software (e.g. SyncToy) or managers (e.g. Windows off-line files synchronisation manager).

Notably, participants mostly only synchronised a selection of information, namely current work (e.g. current projects, writing documents and notes, assignments) and important documents that needed backing up (e.g. photos). Some work was left unique to a device and not shared with other devices (e.g. programs and movies only accessed on a specific device). It was telling that though users wished to synchronise and back up all important information, sometimes the planning and effort required to transfer the continuously changing information hindered them (e.g. *“I have all the papers I’m reading... it’s really bothersome with synchronising them... I’ve been thinking of copying that over to the laptop.”*).

Some of the participants employed alternatives to direct information synchronisation, including emailing important documents to themselves for access on any device that is connected to the Internet or keeping selected documents and calendars online on web sites (e.g. *“When I do research, I usually get those URLs and put it into my Gmail. I can access it anywhere... I save all the documents that I do... everything [documents] I email myself.”*, *“I have a calendar online... because I don’t want to have to synchronise it between devices.”* and *“I set up a wiki for all that stuff [projects, next actions] for my PhD, so I don’t have to synchronise things between devices.”*). These alternatives were mostly pursued to reduce the effort, time and planning required to actively synchronise information between devices, rather than any other benefit provided by the alternatives.

Participants organised their documents largely in folders on their computers, at times making use of multiple drive partitions as well. Documents were structured according to categories and sub-categories in the folder system, as well as arranged according to projects (e.g. according to the GTD organisation system),

time, and/or year and subject. Some information was stored and organised online, such as calendar information, project and task information (e.g. as part of a wiki), shared documents on online services like Google Docs, and documents as attachments in email (where current working documents were invariably in the most recent emails). This migration to online versions of storage and access largely occurred to reduce the need to actively synchronise items, make use of an easy tool for creating an annotated project management space (as with the wiki), and facilitate document sharing (as with Google Docs that a participant used to share her financial budgets with family members).

Information relationships and work context

Participants had several ways of relating documents to one another. At the basic level, they stored related documents in the same folder, creating a hierarchy of folders that identified user categories or projects. Participants applied various naming schemes for the folders, adding dates to folders and to files (e.g. dating weekly reports or indicating last update dates), adding specific details like location and time or artist information to picture or music folders, and even adding goal or task information in the folder name. On occasion, file placement on the desktop was also used to relate documents.

At a further level, some participants held copies of a file in multiple folders, if the file belonged in more than one category or project, and kept these synchronised according to the last update. Another participant used a system of embedded links to files, where one can navigate from one file to other related files through these links. In this case, related files were explicitly linked to each other and accessible through one another.

Where possible, most participants used simple, available ways of storing information about their work context for easier retrieval of information. This included incorporating details into the folder or file name as mentioned before, as well as tracking certain details within the relevant files (e.g. writing time of last update and location source within certain files) and keeping separate files for tracking contextual information for a topic or set of files (e.g. keeping a separate file for articles that have been looked at, with title, author and source information). On the whole however, these participants felt they had to largely remember the details surrounding their work, as there was no way to properly

track the contextual details (e.g. *“I don’t know how to do it... I try to remember [these details]”*).

A couple of participants had however developed more complex mechanisms for tracking work context. One participant annotated documents with various metadata indicating the contextual details around the work. The metadata, set up as hyperlinks, allowed navigation along those links to the related files or information. Another user used a wiki with dedicated pages for each project, and provided work context information on the page through notes, an outline, next actions, deadlines and links. These wiki pages allowed the participant to relate documents and work context on a web of project pages, according to David Allen’s GTD action management method (www.davidco.com).

Tracking and annotating work

The background questionnaire also asked about any explicit information tracking and annotating participants carried out. Information tracking can include keeping track of events, to-do lists, tasks and goals, using any method or software. Work tracking was largely a manual affair for all the participants. Half of the participants kept a to-do list as a simple file or on paper, which they updated as necessary. Occasionally, participants had different to-do lists for each of the projects or project folders they had. The remainder of the participants kept a to-do list using email, whereby they either emailed themselves items whenever something came to mind, kept a to-do list document that they continually updated and emailed to themselves, or kept an ongoing email to-do list that they updated and forwarded to themselves. The email version of a to-do list allowed these participants to have access to the things they needed to do or look up on any device with Internet access, wherever they were. One of the participant’s to-do list was largely incorporated in her wiki project pages in the form of a list of project next actions.

None of the participants used any major software for tracking their work (like Microsoft Outlook or Entourage), but many of them did use a calendar system, such as Google calendar or another online calendar system, a calendar application on a mobile phone, a paper diary or even a wall calendar, for listing meetings, events and deadlines.

Annotating information can include annotations for the physical workspace and physical documents, as well as the electronic workspace and documents. Example annotations in a physical workspace are calendars, post-its with notes or reminders, colour-coded folders, tags and so on. Electronic documents can be annotated with information in file names, category and keyword properties, notes in a document, email or an action list. In the study, participants differed in how they marked their physical workspace and annotated their documents. They used notice boards, post-its, coloured stickers and colour coded binders or folders for tracking notes, marking information of interest, archiving information, and relating and categorising documents. For example, one participant stuck post-its to his computer with important notes, several participants used colour-coded folders to store related documents for a particular information category, and several other participants used a notice board for a wall calendar, flyers and information maps. For many participants colour was used as an important tool to find and identify information (e.g. *“I use mainly colour [for categorising documents]”*), and was even used in the electronic document space.

Not all participants actively annotated their electronic workspace or documents other than with the desktop placement of items and naming schemes mentioned earlier. Some participants made use of virtual desktops to separate their work areas (e.g. *“I have several desktops... I can sort things into desktops, like all my programming is in one desktop, all my private things in another, Internet in another”*), which allowed them to separate tasks, as well as keep personal items and work separate. The virtual desktop also supported task switching, without requiring the user to open all the necessary applications and documents again. One other participant annotated all his electronic work with specialised code and metadata that created a trail of related information items for navigation.

In all these information management activities, participants have shown some similar and some differing methods and habits. Where these methods and habits differ, they highlight each individual’s preferences for certain types of activities and for working in a particular way, whether it involves using a select synchronisation procedure, applying a streamlined action management system, relying on a heavily annotated document space or working largely with categories and colour to separate out work.

INTRODUCTION TO PERVASIVE PERSONAL INFORMATION SPACES AND INFOMESH

Question: How well and easily can users understand the concepts introduced by InfoMesh?

The introduction to Pervasive Personal Information Spaces and InfoMesh occurred through a research concept description and a video demonstration of the InfoMesh desktop prototype. Having read the description and watched the video, participants answered a concept questionnaire to express their initial thoughts on the ideas behind InfoMesh.

Research concept

Reading through the concept description allowed participants to voice their perceptions and thoughts on the idea of Pervasive Personal Information Spaces. The participants picked up many of the basic elements of what Pervasive Personal Information Spaces would create early on, including:

- integrating devices (*“The main idea for me is to make access to the documents, to kind of decouple it from whatever device it is I’m currently using... so I don’t have to worry about which device it [the document] actually lives on or was originally created on...”*),
- automated organisation (*“Organising information without the use of the files and folders... it would be nice... have some system sort it all out for them and show them what’s related to what else”*),
- emphasising activities, context and annotations (*“The annotation would be like the context in the activities I’m working with... it’s good, because if I know what activity I was doing when I was doing this... I’d know what this document is about without looking for it... sometimes just file name is not enough”*), and
- personalising the interaction experience and shifting away from information management (*“Well, it sounds like a really good idea, like how you aim to personalise the computing experience... I just need to worry about my tasks... not managing my documents”*),

Participant comments were quite positive about the concept, expressing that *“it’s a complete change from what it is at present”*. Remarks also underscored the importance of shifting towards how people naturally think (*“The need to shift*

from devices and container-like notions of folders and directories ... [to] be much more content oriented, because that's the space in which people think").

After the introduction to the concept, participants also brought other thoughts and questions forward, related to how automation would work for understanding context, how the concepts would work out technically, and what the interaction with their information space would be like. The video demonstration tried to bridge this gap, but prior to that, participants were asked to remark on their expectations and favoured solutions to these questions.

Participants tried to express how they would like or expect the underlying ideas relating to work activity and context to be supported by computing devices. This helped in understanding how users would naturally visualise the conceptual model transposed onto everyday device use. Their thoughts would show whether or not the conceptual ideas were transformed into an implemented solution appropriately.

Their ideas largely fell in line with how InfoMesh was developed and focused on creating seamless networking between devices with automated and co-ordinated synchronisation of information, providing a search facility that took annotations and context into account, and personalised customisation that changed with time along with the users (e.g. *"[Devices] networked to one another, and to transfer the information with no input on your part – so if you organise on one device, straight away that gets mapped over to the other one"* and *"Shift from being technology-centred... and move into being more user-centred... we're all different... what's good for each person needs to be more customised to that person... the mere fact that people change over their lives... the current technology isn't very attentive to that")*).

InfoMesh demonstration

The InfoMesh video demonstration showed and briefly explained the InfoMesh interface and main views to participants. The video introduced the participants to one specific implementation of Pervasive Personal Information Spaces and elicited their preliminary views of the InfoMesh desktop prototype.

Participant responses emphasised the organisation of documents in InfoMesh according to a context, like time or a map, and having multiple views for providing contexts for work that match certain criteria and that support easy navigation between those contexts (e.g. *“Good way of organising your documents...”*, *“The user can have some kind of spatial view of the documents... for certain criteria... the timeline view and the map view”* and *“Prime function that I see... is providing a kind of navigation, how to get back into a context which you want to do something in, and reduce the effort that it takes to get back into that context”*).

Participants also singled out other elements that were important to them, like colour-coding, customising views, annotating and clustering documents, switching tasks and contexts with minimal effort, adding notes to the workspace and adding action markers that performed a visual reminder function (e.g. *“Different documents that have been annotated with context information, the system provides a way of working with these documents, searching for them... adding more context information, grouping them”* and *“I like the fact about the notes... exclamation marks... visually it is reminding you... and you can colour coordinate it [document] as well”*).

When it came to InfoMesh use, participants had several views. Most of the participants wished to have a system like InfoMesh that supported annotations, tracking documents across time, easy task switching and visualising information according to contexts like a map (e.g. *“Rapidly moving between different ones [activities and work contexts], because your mind works that way or because you get new thoughts”*). Others felt they would selectively use certain views over others (e.g. *“It [a system like InfoMesh] would be nice to have... I think what I’d be using most would be the map view... I might be using the timeline view as well”*). One participant felt it would take time to get used to the idea of having views that were so different from the current hierarchical folder views, though she liked the views and felt they would give her a better *“friendlier”* perspective on her documents.

EXPLORATORY TASKS: INFOMESH DESKTOP AND PDA VISUALISATIONS

Questions: How well and easily can users understand the visualisations presented by

InfoMesh? What are some of the usability issues in the current InfoMesh visualisations?

The exploratory tasks had participants work with the InfoMesh visualisations (both prototype and paper versions), after reading the corresponding scenarios. The desktop views and many of the PDA designs matched the scenarios directly. Some of the alternative paper designs for the desktop visualisations and the remaining PDA designs provided supporting views with a different activity or subject focus.

The exploratory tasks provided information on several levels. Firstly, they gave insight into participant thoughts, understanding, interpretation, preferences, interaction and use for the various views and their content. Secondly, they helped determine the usability issues present in the designs.

InfoMesh desktop visualisations

Participant thoughts varied both with the visualisations they considered and their own preferences for working and interacting with information. Their thoughts and views are now summarised and presented for each InfoMesh visualisation type.

Activity View: Participants considered the activity view for Lisa's "Poster Competition" and an alternative paper design for the activity "PhD Design Specifications".

A) Understanding and interpretation: Participants followed most of the view elements and content instantly, such as the timeline overview, document chronology, document clusters, future timeline segment and colour-coded documents (e.g. "*It shows you can arrange thumbnails, I like that. It's quite good, because there are groups or sub-groups within one project. Here it [a document cluster] will be I guess the extra poster designs, and these documents on how to create good posters and things, and some information related to that poster competition*"). Elements that took longer to grasp included a future time segment for reminders and the workspace time delineation, which abstracted days of little work as slim grey bars in the workspace chronology. They interpreted the view as giving information about the work done and the progress made in an activity, relating documents to one another within the activity, and providing a way to

retrieve documents by remembering the context of work carried out at the time (e.g. *“This is like the research you did [pointing at the research part of the workspace], and then [you] start to actually make the poster [pointing at relevant area on the workspace further down], and then start to make the poster and then email it...you can understand what you’ve done”,* and *“I can see that [the activity] it was a bit slow in the beginning of the days. I can see there were some days where there was no work on it at all, I guess those two lines there are a week-end, because the next day is a Monday, and then I can see that on Tuesday there was lot of activity on this project”*).

B) Content and use: Participants felt that when working with one’s own documents, the view becomes useful to retrieve documents, especially as file names don’t indicate enough about a document. They felt the activity view would be useful or helpful for activities like writing a paper for conferences, large projects, research and activities with various deadlines, as it allowed them to scan their work across the timeline (e.g. *“It would be useful for my research... I think it would be useful for every task I do... I’m really like a time-oriented person... I like to know, on this day, what did I do, what did I worry about... knowing what related thing I did”* and *“I can definitely use this with my assignments, my research, and if I’m doing anything that I’m researching just for hobbies’ sake as well, I can put them all together”*). They also advocated the view’s use for activities like travel planning that could then be shared with others, for bookmarks and as a calendar tool (*“Like if I’m trying to book an online ticket, I’ll put everything... like the cheap flights I get, I can compare them with each other, and put a note with it and see what I’ve done... just track an activity and store them together”*). However they indicated that it wouldn’t be useful for activities like gaming, watching movies or listening to music.

C) General reactions and preferences: Participants generally liked being able to add notes to the workspace, colour-code and group documents. The use for these elements varied with participants. Some liked to colour-code documents to signify their importance, others emphasised grouping related items (e.g. *“The colour coding is noticeable, and I would probably use it a lot”* and *“I think that [grouping] just works out well with the way I think and structure and deal with*

having groups & sub-groups within there, and that would mean I could use groups, the spatial distance between clusters of groups to set apart the larger groups, and then I could mark documents with the colours as this is a very good one or a very important one”). Many did want to see the workspace notes displayed clearer and more completely. Participants had varying view preferences: some preferred to see more text than image (in the form of thumbnails), whereas others preferred having a more graphical view; some preferred the timeline structure over the spatial grouping, whereas others valued colour-coding and spatial document arrangement over document chronology (e.g. *“I think the day view might help me... as I might not really care about the actual timestamps... I might recall that I looked at it [a document] the day before a meeting...”*).

Social View: Participants primarily looked at the social view for Lisa’s “Art Group” work (which is highly graphical), before considering an alternative paper design for work from the “University Group” (which is more textual).

A) Understanding and interpretation: Participants identified the view as providing information about documents that members of a group worked on or shared, using a graphical representation and colour to show who items belonged to and which documents were shared (e.g. *“It shows a network where user can see files by user... documents near line are documents to send or work on collaboratively”).* They also interpreted the view as a collaborative tool for working on group projects and sharing documents, making inferences about who did or shared what work (e.g. *“It’s all artwork... Lisa did this [pointing to document] and Gladys, me and Yuko worked on this [pointing to document]”).* They quickly grasped the meaning of the view elements, such as the representation of group members, and arrows indicating relationships and pathways for information sharing. Elements that were harder to understand were mostly in the alternative, text-oriented design for the view. These included the ‘colour box’ representation of document sharing and the miniature notice board for sharing pieces of information with group members through notes and action markers.

B) Content and use: Participants felt the view lent itself for use with group projects, where documents could be shared with others according to user settings for access control. Examples of use mentioned included research work and co-authoring papers. They also stated that the view would be useful for sharing

information and documents with friends and family, alongside group work for school or office work (e.g. *“Easy way of sharing files... sharing documents for work... writing a conference paper together”*). They explained that the view would allow users to quickly see what each person in the group was doing, creating or sharing (e.g. *“Here Dave is sending links for others to look at”* and *“Each person is separate and each has their own documents that they have created... see what each person is doing”*).

C) General reactions and preferences: As with the previous view, participants generally liked being able to add notes to the workspace, move and arrange documents in the graphical social view. Individuals predominantly preferred the graphical view depicting the group, group relationships and related documents over the textual representation of the same information (e.g. *“I like arrows better than the lists... prefer graphical information”*). They felt the alternative textual design provided too much information, obscuring the human relationships that the graphical view illustrated with arrows (e.g. *“I like the other one [graphical view] better. It gives a better picture... [this] design is not intuitive enough... too much information”*). Some participants didn't find the thumbnails of the documents that useful in the graphical view as they preferred to shrink them in favour of adding other contextual details such as time. Most others though preferred the thumbnails to quickly identify items, especially as the represented scenario dealt with artwork sharing in a group.

Map View: Participants worked with the “NZ Vineyards” activity's map view, and at the end an alternative paper design for the same view. Though the underlying maps shared by the views were the same, the design presented details with icons and text, whereas the active visualisation supplemented the textual information with document thumbnails.

A) Understanding and interpretation: Participants understood that the map view provided users with a way of relating information items within an activity to a specific location, in this case, of relating web-sites of various vineyards and related information items with a region or location in New Zealand (e.g. *“Web-sites are related to location... this vineyard is in Gisborne”* and *“Where the documents are located relates to where the vineyards are”*). They also interpreted

the view to provide supplemental information for activities that had a location context, beyond the information provided in an activity view or by using a hierarchical folder system. They felt that as *“the underlying context [the map] can be rich”* the view offers far more information about the documents. Similar to the previous views, participants followed the use of grouping and annotations, and saw colour coding as a way to identify related information items. In the case of the “NZ Vineyards” activity, the colour-coded groups identified different types of vineyards. Several elements that the participants felt were vague about the map view included items that were placed on the map in locations that didn’t make immediate sense, such as on the ocean area of the map. They were also unsure whether items were located where their document title started or ended. (In Lisa’s activity, the few items placed on the ocean referred to the entire activity, and other items were loosely connected to a region on the map without seeking to specifically associate an item with a town or city).

B) Content and use: Participants felt that activities emphasising geographic or virtual locations would benefit from a map view of the underlying information. They also indicated that wherever information could be visualised in association with a context like location, the view would be preferable to a folder listing (e.g. *“Where you can visualise it [by location], it would be good. I’d rather have a picture than a list of folders”*). Examples of use mentioned included using the map view for photos (using digital cameras and GPS) to automatically place travel photos on a map, for an overview of literature on a category map with clusters, for places visited on a road trip, or for any situation where you can create your own map to arrange and relate information (e.g. *“Handy to have when in local context with a PDA on hand”* and *“It would be even more useful for photos... cameras and GPS... with auto-placing of photos on sites”*).

C) General reactions and preferences: Preferences varied with participants, some preferring thumbnail detail for item identification (as displayed in the active visualisation, which emphasised thumbnails over document titles) and others preferring more text and icon information for documents (as displayed in the alternative design). The former set felt that having the thumbnails provided a better overview of the space, allowing the user to zoom in to a particular region to

look at the document titles for that region in detail (e.g. *“I prefer the thumbnails and zooming in for reading... otherwise confusing... It’s a good thing to have [the] overview”*). The latter set of participants felt that thumbnails would crowd the map and may be too small to be useful, and that full title information (as opposed to smaller document titles that would require zooming in) would provide more immediate information about the items in the view (e.g. *“Thumbs are recognisable only with frequent use... so better to have more information on the name of the place rather than thumbs”*). Several participants indicated that they would use the map view the most of all the views they had seen so far. Suggestions for improving the view included the ability to draw lines (as planned for the FlexTools markers options) and a legend feature for users to keep track of the colour-coded document groups (especially when returning to an activity after some time).

Other Views: Participants looked at several overview visualisations, which were mentioned in a corresponding high-level use scenario. These included an overview, a work view, a notice board view, a view listing all activities and views, and a universe view. The first three included both prototype and paper design versions, whereas the last two were only available as a paper design.

A) Understanding and interpretation: Participants understood the overview to provide a summarised view of their current activities and work progress across time (*“visual view of all you’re working on”*), while the work view allowed them to work on several activities at the same time. They felt the overview timeline allowed them to interpret and assess when they did certain work, how much work they did, which other activities they were carrying out at the time, and what deadlines they had to keep in mind (e.g. *“[Shows] which project I did when... answering questions about work... see progress [and] context”* and *“She [Lisa] was busy looking for wine bookmarks in Feb 2006”*). A couple of participants were not too sure about having to categorise unclassified items for the work view, though others felt comfortable with associating these items with single or multiple activities with a drag and drop. Elements in these views that were harder to grasp at the onset included the granularity of the histograms and the information they conveyed, as well as the use of the future segment of the timeline. Participants viewed the universe view and the overview of activities and views as giving a

bird's eye view of their information space in terms of interests and activities (*"Good to see it all at once"* and *"Bigger view of your work"*), where the former was highly graphical and the latter was structured and textual. Several view elements in the listing of activities and views however proved to be ambiguous, including the icons identifying activities and views, which in turn made the entire view harder to understand. The participants further understood the simple notice board view easily.

B) Content and use: Participants universally liked the idea of having an overview of their work, as it provided a bigger, visual view of what they had done and what they were now doing. They mentioned a variety of ways the overviews would support work, including as a reminder for ongoing projects, for supporting work continuity when you return to an activity, for retrieving completed activities and work according to time, to quickly access recent material, for viewing work progress and answering questions about work that had been carried out (e.g. *"It's a good reminder for ongoing projects, for continuing where you left [off]... [it's] easy to reopen last files"*). While some participants felt overviews would be useful to have for all computer-supported activities, others felt they would not use it for every task they worked on (e.g. *"More for studies and work... to see what's been done so far... almost everything computer related"* and *"I don't mind this idea... [but] wouldn't use this for every task"*).

While a couple of participants felt a benefit in having multiple types of overviews and the perspectives they provided of the information space, the remaining participants showed strong preferences for certain views over the others. The overview was appreciated by all, whereas the work view's use was rated slightly lower. Most participants then finally favoured either the universe view (graphical representation) or the listing of activities and views (textual representation), but not both (e.g. *"Universe view is better than this [listings of activities and views] view... it's more graphical"*). One participant indicated that though some of the views may require time to get accustomed to, they were flexible and would work like mind maps, allowing people to use them in different and new ways (e.g. *"People will take to this [Universe view] more... people will invent [new/other] ways to work with it"*). Finally, the notice board view also elicited different responses, some welcoming its use because of the visual nature of the reminders

(as opposed to a textual to-do list). Others however didn't feel they would truly use it alongside their existing calendar or list based reminders, specifically as the notice board did not provide an active reminding function and as due dates and annotations could largely be worked into the various other InfoMesh views themselves.

C) General reactions and preferences: Participants showed strong preferences in looking at the overviews, especially with relation to a graphical representation versus a textual representation, or a spatial versus a hierarchical or linear representation of information. They often indicated which views they preferred, disliked or found similar (in which case they felt a particular view was superfluous or that one main overview was sufficient). The only constant here was that each participant varied in his or her likes according to their own work habits, natural intelligences and information behaviour. The extent to which they found the overviews useful also varied. Some wanted the benefit of multiple views on the information, whereas others wondered whether each additional view would add to the complexity of using InfoMesh. Universally, participants preferred the prototype visualisation of the work view to its alternative paper design. One suggestion made was to extend the overview's timeline so that more deadlines and notes could be added. Participants concluded that a major strength of the overviews (such as the universe view) was to see all their active projects and sub-projects in one place with the added ability to group and relate various projects and information objects. They emphasised both the visual and broad view of their work that the visualisations provided (*"It's visual... they are all there together... it's a broader idea of everything... this is your own space... [your] interests and activities"*).

InfoMesh PDA view designs

Similar to the desktop visualisations, participant opinions for the PDA designs differed with the designs they looked at and their preferences. Participants also voiced their thoughts about the PDA designs with the desktop visualisations in mind. Participant thoughts are once again summarised per InfoMesh visualisation.

The views expressed in this section supplement participant views given for the corresponding desktop visualisations, and therefore focus specifically on the elements introduced or adapted for a PDA.

Activity View: Participants looked at a paper design of the activity view “KB Art”. Participants felt the view was appropriately close to the one provided through the desktop implementation. They followed the idea that only selected documents would be available on a PDA and that available and non-available documents were differentiated on the workspace through the presentation of a thumbnail and checkbox. This presentation was not grasped immediately by all participants and so one participant indicated simply having active and greyed out thumbnails may simplify it. Several participants indicated that the timeline was less clear compared to the desktop visualisation. Various participants also indicated that initial exposure and use of the visualisation would make the version more useful, especially as some of them did not use their PDAs regularly and were unsure how they would use the visualisations on their PDAs (“*Need to know what everything is... once known it’s useful*” and “*Don’t have experience with it so don’t know how often I’d use it, [but] I can see the sense of it*”). The visualisation was deemed potentially useful for certain contexts, such as when travelling and having instant access to specific information items and notes in context (e.g. “*There’s a context this would be useful in... [it’s a] challenge to pull it off*” and “*Can access it on a train... look into the notes. Anything on the computer is right here. You have instant access to it.*”). The challenge mentioned was to design quick overview and retrieval of the large underlying information space, for example through speech retrieval of information.

Social View: Participants looked over a paper design for the “University Group” social view, which is the PDA design version of the alternative desktop design (textual non-graphical format) for the same view.

Most of the participants didn’t like the non-graphical view, especially where they preferred the graphical desktop visualisation, and so favoured a similar version for the PDA as well (“*Not the one I liked... I prefer the more graphical representation*”). They felt that the categories related the documents to various group members in the non-graphical version, but did not show relationships

among the documents well. They indicated that a social view would be useful in situations where you carry your PDA when meeting with people, for example supervisors and colleagues, and could discuss and share documents. One participant also appreciated having access to items shared within circle of friends on the PDA (especially with smaller information items such as photos, contacts, links and notes that would be handy on the go).

Map View: Participants considered a paper PDA design version of the “NZ Vineyards” map view, which corresponds with the desktop view for the same activity.

All of the participants liked the map view for PDAs, especially as an accessible overview that could be used on the go. They indicated that the view would be useful when travelling, as a way of having location based information available on a PDA. Other examples of targeted use of the view included using the view for contact details, notes and downloaded web pages, and for creating mind maps and other work that users may prefer doing on the go or away from the desktop or laptop computer (“*Might be useful for notes or downloaded web pages... contact details for wineries [when visiting them]*” and “*Useful for mind maps [using a virtual map view to annotate]... I don’t want to always do it on the computer*”). Several participants suggested that the PDA version of the map view did not need scroll bars as it had a navigational overview box at the top of the screen. Participants also stated that the view was useful as a representation by itself with little textual detail necessary and without the underlying documents themselves (such as in the case of “NZ Vineyards”, where all items were bookmarks). They felt that the view served as a good quick overview in that way (e.g. “*No text is needed... the overview itself is good*” and “*It would be enough to just have the representation and not the full documents*”). Another participant suggested to indicate the number of documents on each side of the screen to assess how much detail was on the non-visible portion of the map.

Overviews: Participants finally also viewed the paper PDA design versions of the overview, work view, overview of activities and views and universe view.

Participant opinions on the PDA overviews were very diverse. Some once again related to their preferences for certain views and for graphical versus linear or

hierarchical information presentation, whereas other opinions related to the amount of information displayed on the screen. Due to the restricted screen spaces, participants wished to see some of the views simplified, as certain elements sacrificed one useful feature for another. Suggestions included limiting items to thumbnails in the universe view at the first zoom level for a quick overview, reducing the number of scrollbars on several views, listing activity pockets on the work view without any document content, showing only the activities at a specific point in time on the overview (as selected by the user on the timeline) and restricting InfoMesh's PDA version to fewer views. Participants did feel that it would be useful to having one or two overviews of their work on the PDA (an overview combined with either the universe view or the listing of activities and views). They explained that though they might not work on the actual underlying documents themselves on the PDA, they may write notes and relate these to their work on their computers, or just keep track of their work and the actions to carry out next.

Usability issues

In the course of the study, specifically during the exploratory tasks segment, the participants shed light on various usability issues in the InfoMesh visualisations. Significant and pertinent usability issues, improvements, and participant suggestions are now summarised below according to several categories, dealing with views and view content, presentation and interaction, and finally, user suggestions. (An important distinction is made here between issues brought up by the participants with respect to view presentation and interaction versus their view preferences. Participants had clear preferences for graphical or non-graphical versions of the same view for example, which dealt more with how they personally thought and worked as opposed to the view designs themselves. These preferences have bearing on gearing the interaction experience towards the natural differences in users rather than on issues that need to be fixed.)

Views and view content: From the various views and their alternative designs, select visualisations were clearly preferred over others. The prototype visualisations for the social view and the work view were chosen over their alternative paper designs. In the case of the social view, the alternative design had

too many elements (such as the colour boxes representing sharing) that were ambiguous or difficult to understand. For several views, elements from the alternative design were valued enough to suggest their incorporation into the prototype visualisation (such as supporting contextual document details on the map view and social view). Users do need the flexibility to display, hide or alter various information elements such as dates, larger or smaller thumbnails and so on to offer better support (as is currently planned through the use of FlexTools). This allows users to adapt the view to their activity, so representational and contextual elements are emphasised that particularly inform and differentiate items on the workspace. The study also supported the idea that InfoMesh should provide a variety of maps for the map view that users could start out with, before creating or adapting their own.

Though the various overviews of the information space had their benefits, several participants felt the large number of views could potentially result in a steeper learning curve. As the user preferences between the various types of overviews also varied, exploring and evaluating the various designs in more detail would be useful before incorporating them all in a first implementation of Pervasive Personal Information Spaces. Next to reducing the number of visualisations for a first system, the important features in the remaining views also needed to be refined and functioning accurately (especially as InfoMesh has to function as an ubiquitous, everyday tool).

Work with the PDA visualisation designs largely supported the same findings from participant interaction with the desktop visualisations. With the PDA views, it was clear that an initial implementation of InfoMesh should simplify the main views, limit the overviews provided to one or two, and support a graphical version of the social view rather than a textual one.

Presentation and interaction: Several main areas of visualisation-related usability problems surfaced in the study. With respect to presentation quality, participants emphasised improvements to the resolution (of document thumbnails), legibility (of text alignment when presented with thumbnails, or text clarity when used with colour coding), visibility (thumbnail and colour bar sizing for items), and colour selection (selection of muted and complementary colours for colour coding and grouping).

Issues with presentation detail focused significantly on two elements. Firstly, the workspace notes (and by extension many of the action markers) needed to present more of the note content and less of the image detail on the workspace itself, so that the content is largely visible from the workspace without requiring access to the annotations pane on FlexTools. Secondly, the ambiguous icons depicting activities and views in the listing of activities and views needed to be changed.

Finally, to maintain presentation flexibility, participants also expressed the need to personalise thumbnail display and sizing on the views alongside information elements like titles, file details and colour as provided with FlexTools. Allowing users to limit or simplify the amount of information presented on a view was also important (e.g. limiting the levels of information items provided on the universe view). Some of this can be achieved using the FlexTools feature. Otherwise, information items presented on the view can be limited according to the zoom level set for the view, with zooming in displaying more detail and zooming out fading out lower level detail.

For the visualisations for the PDA, participants additionally wanted some of the views simplified. Pertinent to the first implementation of InfoMesh for PDAs are reducing the number of scrollbars on views like the overview and the work view, miniaturising activity pockets and hiding their content, simplifying the diagrams in the activity view timeline and adding a scrollbar for the timeline, and signalling document availability in the activity view through thumbnails and greyed out icons only.

Suggestions: Participants also made some specific suggestions for improvements in InfoMesh visualisations. These included the following:

- Providing more information in the timeline bars in the activity view when the user has not done any work or has been away on holiday (e.g. using text or an icon),
- Playing out the timeline as a sequence of documents (displayed in miniature form) to help locate an item, especially for old activities,
- Creating an active object of every item presented on the view workspaces, so that they can be emailed or linked to and so on,
- Offering a legend feature for the views to help identify item colour-coding categories, especially years after an activity has been carried out,

- Providing a way to scan or pan the timeline for looking ahead or backwards without losing the current position on the workspace,
- Offering a view mode (e.g. a “meta-mode” feature) that provides contextual help and descriptions for understanding view elements like timeline histograms and the future timeline segment, as a beginner might not fully comprehend what these elements are,
- Allowing users to create and add their own marker icons to annotate the visualisations,
- Supporting PDA views with an option for hiding document content on the overviews, providing an indicator to show the number of documents outside of the visible screen space for map views, and offering users a way to navigate the overview timeline so that the activities listed match the time selected, and
- Developing a simple set of related visualisations for mobile phones as well in the future.

Participant perspectives on InfoMesh visualisations

Participants answered several questions to provide insight into their views of the visualisations as a whole. They felt that the information relationships offered in InfoMesh were useful by tracking and matching what they did and the work they actually carried out. They found the information interaction to be freer and less constrained, and valued the visual view of their information, with decreased emphasis on text alone as a retrieval cue (*“I like the interaction, cause you can move everything freely, you’re not constrained... I don’t like text, I think visualisation is more important, so less text is good... if it’s all textual... it makes me have to think... I prefer looking at it visually”*).

Participants felt that the visualisations organised and presented information in a better way by using time, maps and people, and by using colours, grouping and notes. They were of the opinion that the rich visual content would allow them to assimilate information much better, reminding them of what’s there in their space (*“They’re [the documents] organised and presented to you in a much better way, with a timeline... colours, the maps.... [it] is just recording the information you access and organising and presenting it to you in a visual way... you can assimilate everything better, it’s just instant, you can just see it... it reminds you of what’s there in your space”*). Participants also appreciated having multiple

views or altering views on the same information, which one could only mimic in limited fashion in the folder system by creating several folders and organising them carefully. They believed that these ideas and capabilities would support users better, by freeing them to create their own knowledge space, especially as everyone would organise and perceive their information differently (*“I think that people, the users will see and sense you’re providing a new canvas for them to be able to take knowledge and express it in ways that they would have felt confined and constricted before”*).

Participants had various views when considering using the visualisations on a daily basis. According to each participant, certain visualisations would be used more than others as detailed in earlier sections. Several participants indicated that they would use the visualisations to support nearly all types of work, such as studies, work, hobbies, finances, planning, and sharing information in a group. Other participants preferred to use the visualisations mainly for high-level information access and interpretation of their information space as well as information synchronisation, rather than for daily information management (e.g. *“I would more use it for getting an overview.... I’m not sure I would actually use it for daily document management things”*). These participants were unsure how or how far the system would be used in practice, especially due to the reluctance users may have in learning a new system.

A couple of participants felt that the benefit of the visualisations would also lie in the extent to which they would help in generating ideas, composing and aggregating content, especially as they brought together various pieces of information for visualisation and interpretation of work at a conceptual level. It was clear that participants would require more time exploring the views to comfortably understand them, evaluate the views’ appropriateness for their work and their everyday information interaction (*“I’m not sure how easy it is to use it, to learn it or how much effort it will take... [knowing] is my investment worth what I receive”*).

Overall participants felt that the PDA and desktop visualisations matched up and were consistent with one another, with the PDA visualisations appropriately providing a simpler view of the information space. Participants did advocate simplifying the PDA visualisations further by for example reducing the amount of text and scrolling in many of the views to accommodate the limited PDA screen

space. They felt that the PDA views would be especially useful as high-level representations of the information space, for example with the map views and social views, supporting information interaction and sharing on the go (e.g. *“They’re useful for having information [available] when carrying it [the PDA] around”*). Participants thought that the desktop views would support them in creating, populating and accessing their information space, whereas the PDA views would help them with viewing, reviewing and reminding at a more conceptual level.

COMPARATIVE TASK: INFOMESH AND HIERARCHICAL FOLDERS VIEWS

Question: How do InfoMesh views on information compare to current hierarchical folder views?

The comparative task gave participants the opportunity to compare InfoMesh views for several activities (related to the research poster competition, PhD specifications and NZ vineyards’ documents) with hierarchical folder views for the same information.

All participants felt that the folder view of an activity’s documents provided clear file details regarding size, modification and creation dates, document types (e.g. *“For the folder view... I can see the filename, size...type... and time when it was modified... [but] you can’t rely on the date-stamp because as soon as you start copying it’s all gone anyway”*). The strength of the folder system was seen in the ability to sort according to these details and to readily create sub-folders for presenting a hierarchical view of documents. Participants indicated that the folder system affords a quick way to access a file, but only if its name and location are remembered. One participant stated that only the most detailed naming scheme would allow the user to find a file based on a context too (e.g. incorporating a geographical location into the bookmark names for the various NZ vineyards).

As for a major weakness of the folder system, participants said that names are largely the only true indicators for a file within the hierarchy. They stated that as there are no annotations or further contextual or personalised information from the user’s work, the document listing is *“technical”* and *“detached”* from the user, with few indications of priorities, document importance or document relationships (e.g. *“There are no notes, there is no kind of your own input... it’s detached from*

you, it doesn't kind of prioritise anything... colour coordination, there's none of that... they all look similar to each other... everything blurs into the other... it doesn't stand out..."). As a consequence, participants felt that the folder view is not that useful in carrying out and making sense of work (e.g. *"Folders are technical... not exactly what you need when doing a task"*).

Participants listed several characteristics as strengths of the InfoMesh visualisations. They felt that the visualisations allowed users to relate and annotate information in a variety of ways (through the document holding area, colour, notes, markers, grouping, maps and time), which allowed easier access and interpretation of the information within the work context. Where file details like size and timestamps were hidden, participants felt that the visualisations functioned instead on a higher semantic level (*"What is obviously lost is the file size, which I don't care about anyway... It shows the time in a way that I can really use it... but as a relative amount as before or after some other document... It doesn't just show the modified times, but shows all of the times it was accessed... I get the colour coding... the notes and other icons [markers]... the grouping... and annotations..."*). Participants indicated that the relative and embedded way of presenting information items, time, maps and people, was of more practical use for carrying out activities and showing documents according to where they belonged. Participants further emphasised that unlike the folder system, the InfoMesh views were not similarly tied to one location or device, providing the same personalised access to information from anywhere with little extra effort.

The weaknesses of the InfoMesh visualisations were largely mentioned as the strengths of the folder system: clear file details were not readily available on the view workspaces and the time taken to access a remembered file could take much longer in an expansive view than in a hierarchical file system.

Participants felt that these often opposing weaknesses and strengths of the folder system and InfoMesh visualisations were the reason that the two complemented each other very well. They were of the opinion that it was important to have richer, more informative views of their document space than that provided by the hierarchical file system alone (e.g. *"Users need to have significantly different views that the one we have now...I'd rather have a richer, more informative*

space”). Specifically, views like in InfoMesh that emphasised user work and work context.

When considering using InfoMesh-style visualisations, half of the participants felt that considering their work habits, they would prefer using these kinds of visualisations in place of the folder system, once they were updated according to the usability issues mentioned earlier (“*I might not use folders anymore*” and “*I don’t see why that would be necessary when this is there. They do complement each other. I wouldn’t go back to that. Unless the software loses information*”). The remainder of the participants felt they would use InfoMesh-style visualisations alongside their current use of the folder system, benefiting from the features and strengths of both types of views, with one participant clearly stating that the folder system would have their preference in that situation (“*I wouldn’t mind having this additionally and learn it if it’s useful*”). Though they talked about the usefulness of InfoMesh visualisations for desktops, participants were not too sure how often the PDA visualisations would be used and how useful these would be in daily computer interaction.

END OF STUDY QUESTIONNAIRE

Question: What are user views on ‘Pervasive Personal Information Spaces’ (as exemplified by InfoMesh) and their use, especially in providing access to their electronic information and supporting high-level activities?

The final questionnaire elicited user views on the concepts and utility of Pervasive Personal Information Spaces and InfoMesh, using a variety of statements. Participants first commented on the following concepts:

- Having a single large information space that is accessible from all your devices at anytime.
- Having the system automatically register your use of documents and integrate your documents from different devices.
- Having visualisations that are based on contexts like time, place, device and people.
- Working according to activities instead of folders alone.
- Having overviews of your activities and documents.
- Annotating your workspaces with notes, keywords, icons and markers.

Participants found having access to their integrated information space from any of their devices one of the most useful aspects of Pervasive Personal Information Spaces. This reduced user effort in synchronising and updating information across devices. However, participants did mention the need for device-tailored information access and visualisations. Furthermore, though access to an integrated information space was useful for various activities or work contexts, sometimes it was unnecessary or even unwanted, for example having access to personal files on work computers. All participants welcomed automatic tracking and integration of documents into their information space, as long as tracking options were in their control (for example to switch off or adjust automated tracking so as not to include private or uninteresting material).

Participants also invariably appreciated having visualisations that rooted information in the work context using time, location, devices and people. They felt that the contexts provided the most important organisation or structure to the information in an activity, as in the real world activity centres around time, places and people (*"It's context that provides organisation... it gives structure to information... usually the things by themselves are not as powerful to do the structuring... the ones to focus on are time and place and maybe people... you can remember you're doing something with somebody, or you're doing something that's related to a place, and you can almost always remember the approximate time... you might not remember anything else"*). However, several participants felt that categorisation into activities or folders was largely how a person thinks, as some users already name folders according to activities. With Pervasive Personal Information Spaces however, they felt that activities matched user work better as the activities were enriched and more memorable due to the inclusion of contextual details (e.g. *"It's not just the work, it's the context of the work... more visualised... so that it is as memorable as the work is... that enables people to get back into the context quickly"*). One participant did highlight that though a user would follow his or her information space comfortably, another person (such as a friend or colleague) may find it much harder to make sense of the same views due to the heavy personalisation.

Overviews were well liked as a reference and reminder for past and current work as well as and concurrent activities (*"Very helpful... chronological reminder of what else you're doing"* and *"It keeps a reference of what you did... [otherwise*

it's] hard to remember"). Participants felt that the overviews organised their work at a higher level, however, they emphasised the need for improving the existing overview visualisations. They also felt that overviews would not always be as useful on PDAs, as on desktops.

Annotating views was seen as helpful in personalising, marking and explaining work. However, half of the participants felt their use might be limited according to personal preferences. For example, one participant liked having their notes on a wiki separate from different views, another participant preferred annotating documents only instead of the view space, another felt that annotating the future segments of timelines and workspaces would be of main use to her, while yet another participant felt that the entire unmarked sections of view workspaces were most valuable for annotations.

Participants were subsequently asked to complete the following sentences:

- The best thing about InfoMesh is...
- The most annoying thing about InfoMesh is...
- The ideas in InfoMesh would work, because...
- The ideas in InfoMesh would not work, because....

Participants emphasised that the best things about InfoMesh were the overall vision for Pervasive Personal Information Spaces, the visualisation of information, and the organisation of information according to contexts like time and place, which they felt revealed and highlighted information relationships beyond the current hierarchical listing of documents.

The most annoying things listed included some of the overviews (which were unique for each participant that mentioned it) and the aesthetics of the current visualisations (especially resolution and legibility). A couple of participants also mentioned that the various views might take a while to learn and so confuse the user in the beginning. They understandably mentioned that they would probably only know which aspects did not work practically after using InfoMesh for a while.

All participants strongly stated that the ideas in InfoMesh would work because it reflected the user's natural way of thinking about and organising information, by visualising information flexibly and bringing time, space and people into the picture (e.g. *"It better reflects user's physical workspace rather than the*

restrictive electronic workspace... it's natural", "*It's natural for users to imagine their documents in a visual way and to associate it with different contexts*", "*They're paradigmatic... using time and people and these general paradigms which we are well immersed in in our outer world... bringing in space and time into a world that hasn't used it very well*" and "*I think that's how people think about contexts and stuff*").

Participants felt that though the ideas underlying InfoMesh should work, InfoMesh could be held back by numerous factors. First, they felt that people might be reluctant to try any other system and keep to the folder system. They also felt that a system like InfoMesh may require a lot of time to learn and construct before users could benefit from using the system (e.g. "*Some people are already used to [the] system now*" and "*It may need too much time investment for the user to have the information in there*"). They stated that too much richness in the visualisations might create complexity that is counter-productive in the daily use of the visualisations, specifically on PDAs. Participants further suggested that technical problems (such as synchronisation across various devices, different operating systems and network issues) could hamper its use. Lastly, they felt that as research into Pervasive Personal Information Spaces is expansive, there will be far more years of work required to perfect it.

6.3.4 IMPLICATIONS

The study on InfoMesh visualisations helped evaluate InfoMesh on both a conceptual and practical level. The findings exposed varied and largely positive user perspectives on Pervasive Personal Information Spaces and its implementation as InfoMesh. (Appendix section C.1, Table C-1 summarises the study's key findings as a reference.) These perspectives comprised a set of core views on InfoMesh visualisations, use and usability, as well as individual preferences that highlighted the uniqueness inherent in each user's information behaviour. The former user views set the stage for selecting and refining InfoMesh visualisations and developing the system further before a second user study. The latter highlight user differences that make personalising information-interaction both challenging and rewarding. Each user's preference matches a

work style that better supports their thought and work processes, and ultimately creates a better, tailored interaction experience.

Critically, user views repeatedly underlined the need for a richer and more natural way of interacting with their information space. Participants were positive about user work that was annotated with the contexts of time, people and locations as well as colour, workspace notes and spatial arrangements. They felt that this matched how people naturally thought. The personalised, flexible, graphical presentation of these details further supported work interpretation and continuity. InfoMesh was deemed useful for providing an overview of work, as well as tracking, aggregating and assimilating content. Participants were unsure of its everyday use, which can only be assessed through further exploration and real world use.

The study revealed the complementary nature of the current hierarchical folder system and InfoMesh. In comparing the systems, participants once again underscored the need for a richer, personalised and more meaningful way of working with their information, alongside the more technical and structured hierarchical listings of information.

Participants understood and appreciated the underlying concepts, especially the overall vision for InfoMesh. Their current mode of information management involved many work-arounds for annotating, synchronising and making sense of personal information. Information accessibility also suffered in their ubiquitous computing environment.

Participants highlighted a variety of issues that covered both the usability of the InfoMesh visualisations and potential pitfalls of the system in development. These issues and their preferences helped narrow and refine the InfoMesh visualisations before building the system further.

Several core InfoMesh views were selected for more detailed implementation. Specifically, these views were selected and refined to match participant remarks and preferences revealed through their evaluation of the various visualisations and alternative designs. Limiting the number of views would reduce the initial learning curve. It would also help target InfoMesh prototyping and evaluation more explicitly towards the core characteristics of the Spaces model.

The activity, map and social view as well as the work view and overview were selected for further InfoMesh prototyping. The activity view was refined with

more detailed time delineation and navigation, with the design for the PDA version much simplified. The PDA prototype aimed to simply provide static visual representations initially to provide information context and information overviews. The graphical version of the social view was selected for both the desktop and PDA implementations of InfoMesh. The work view visualisation was selected instead of the alternative design. The overview was selected above the 'all activities and views' and 'universe' views. Participants all showed a partiality to the first, though their preferences differed for the last two. Their remarks revealed that more study would help understand what kind of overviews would be additionally of use, how and why. Finally, participant remarks also supported further development of InfoMesh tools (such as querying annotations) through the FlexTools feature.

A number of the usability issues raised by the study were tackled at this point, including improvements in system icons, navigation options, and thumbnail and text clarity. Other supplementary issues and suggestions, some requiring a greater time frame to implement or more study, were left for the future. These included view content according to zoom-level, expanded workspace notes, a legend for workspace colour codes, a 'meta-mode' for views, and activity history playback.

All together, the findings from the study showed support for the underlying framework of providing context-based flexible views of distributed personal information. Simultaneously, these findings geared InfoMesh development towards the next step in testing the research hypothesis.

6.4 SUMMARY

In the research into Pervasive Personal Information Spaces, evaluation has taken the form of small focus group interviews, two short-term user studies on InfoMesh and an initial reflection on long-term InfoMesh use.

This chapter reported on the first phase of InfoMesh user evaluation, which emphasised the system visualisations and helped evaluate them on both a conceptual and practical level. The study highlighted positive user views on the ideas of Pervasive Personal Information Spaces and its implementation as InfoMesh. Importantly, user views underlined the need for richer and more natural information visualisation and interaction, as approached by InfoMesh through

visualisations of contexts like time, people and locations along with annotations, colour and grouping associations. The study findings also revealed a number of usability issues and highlighted the complementary nature of InfoMesh visualisations and hierarchical folder views of information.

User perspectives and preferences voiced in the study helped in selecting core views and view elements for further InfoMesh development from a variety of view types and designs. InfoMesh was consequently refined and developed according to these criteria, before a second phase of evaluation. The next chapter reports on this second phase of evaluation, which emphasises InfoMesh interaction and use, before reflecting on InfoMesh long-term use.

CHAPTER 7: EVALUATION II

STUDYING INFOMESH INTERACTION AND USE

7.1 INTRODUCTION

The first phase of InfoMesh user evaluation helped capture and refine select core views and elements of Pervasive Personal Information Spaces in a more streamlined, interactive InfoMesh desktop prototype and a basic PDA prototype. This chapter now reports on the second phase of user evaluation carried out on this updated, interactive InfoMesh prototype system for evaluating and assessing the prototype, the underlying Spaces model, and thereby the concepts fundamental to the idea of Pervasive Personal Information Spaces.

The chapter first presents details of the second user study carried out to assess InfoMesh visualisation, interaction and use through the broader prototype, which utilised activities and activity snaps for the persona 'Aran'. Subsequently, the chapter reflects on the long-term evaluation of InfoMesh use, through a preliminary investigation that considered the formulated study plan, InfoMesh use and robustness in preparation for a future longitudinal study.

Each of the user studies on InfoMesh provided a gradual way of approaching and testing the research hypothesis, by helping evaluate the effectiveness of the research concepts in providing improved contextual and ubiquitous access to personal information. InfoMesh evaluation on the whole supported the hypothesis, revealing that context-based flexible views may indeed provide better contextual, ubiquitous access and visualisation of information than the single-device systems in use today, especially as these views corresponded with how people naturally worked and perceived information.

A final discussion summarises the findings from the InfoMesh user studies and their support for the research hypothesis, and briefly considers findings from studies on related developments.

7.2 STUDY ON INFOMESH VISUALISATION, INTERACTION AND USE

The second study on InfoMesh utilised fuller desktop and PDA prototypes to determine participant experience and assessment of InfoMesh visualisation, interaction and use. Participants explored InfoMesh FlexViews and FlexTools on a personal computer and a PDA by working through a user guide and carrying out a variety of exploratory, assessment and comparison tasks. At the heart of all these tasks are the persona 'Aran' and his activities. By interacting with, interpreting

and discussing views of 'Aran's' work, participants shed light on their understanding of Pervasive Personal Information Spaces, and InfoMesh visual elements, interactivity and usefulness. A few user-subjective evaluation techniques provided deeper insight into participants' preferences and behaviour with respect to InfoMesh use in supporting their own recent activities.

The following sections now look at the study's purpose, problem statements and method, before analysing and discussing the study findings. This second study on InfoMesh completes the short-term, lab-based evaluation of InfoMesh, and helps prepare for a longer-term investigation into the real-world use of InfoMesh.

7.2.1 PURPOSE AND PROBLEM STATEMENTS

The purpose of this study was to evaluate InfoMesh interaction and use for the desktop and PDA prototypes, on both a conceptual and practical level. The study focused on more detailed versions the overview, activity view, map view and social view, and this time, also looked at the tools for annotating and manipulating these views.

The goal was to use the observations and insights from the study to determine participant experience and attitudes towards InfoMesh, its use and appropriateness. These observations and insights would once again assist with assessing and refining the underlying design and conceptual model, and preparing InfoMesh for a field study.

This second study is designed to provide deeper insight into the issues explored in the first study. The study, however, now emphasises these issues through participant interaction with the dynamic views presented by more comprehensive InfoMesh prototypes. These issues, expressed as the following questions, will allow the study to test the research hypothesis further:

- How do users make use of their devices to support their activity work? What are the contextual details that make up their work?
- How well and easily can users understand the concepts introduced by InfoMesh?
- How well and easily can users understand and interpret the context-based flexible views presented by InfoMesh on the information space?
- What are some of the usability issues in the current InfoMesh prototypes?

- What are user views on InfoMesh interaction and use? (*This includes interaction with views on the desktop and PDA prototypes, as well as using, manipulating and altering views using the FlexTools feature*).
- How do InfoMesh flexible views on information compare to current hierarchical folder views?
- What are user views on Pervasive Personal Information Spaces (as represented by InfoMesh) and their use, especially in providing access to their electronic information and supporting high-level activities?

Once again, the study tasks, and study analysis and discussion consider and answer these questions in sequence. In answering these questions, this study would expand testing of the research hypothesis beyond the conclusions drawn from the first study.

7.2.2 METHOD

In this second study, participants were first introduced to InfoMesh through a user guide summarising the system that mirrored views presented by the prototypes. The persona ‘Aran’ and his activities then formed the basis for several tasks, where the participants explored, interpreted, manipulated, and compared InfoMesh views. Participants were encouraged to ask questions and discuss their thoughts throughout the study. These discussions provided insight into their interpretation of InfoMesh view content and their opinions on the usefulness and appropriateness of the various views, view elements and tools.

An early pilot study helped fine-tune the user study material (i.e. user guide, questionnaires, participant workbook, evaluator interaction and observation guides), as well as assess tasks and task times. The pilot study showed that the user-subjective evaluation would take a considerable amount of time for the scope of the current study, specifically with respect to the participant pre-study interviews and data collection for subsequent activity snap generation. As a consequence, this segment of the study was simplified considerably. The background questionnaire incorporated the pertinent interview questions, so that this information could be referred to in later tasks for insight into individual use preferences.

PARTICIPANTS

Six participants took part in the second study, which was conducted at the Usability Laboratory in the Department of Computer Science at the University of Waikato. The study ran over six sessions of two and a half hours each, where each session focused on a single participant. The participants were all graduate students in the department.

Corresponding with the target population for the InfoMesh system, the chosen participants were once again computer users with reasonable to high level of computer skills with relation to authoring and gathering documents, managing large amounts of electronic information, and using multiple personal computing devices (such as desktops, laptops and PDAs).

TASKS

The study had six separate segments, which included reading a user guide, a variety of tasks, questionnaires and discussions.. Throughout the study, the participants were able to voice and discuss their viewpoints on InfoMesh and the tasks they carried out.

Segment 1 focused on a background questionnaire for gathering information on participant use of multiple personal devices. Specifically looking at how they carry out various computer-supported activities, and how they relate and annotate their computer-supported work with respect to their work context.

Segment 2 introduced participants to InfoMesh via a brief user guide that provided a background to Pervasive Personal Information Spaces and summarised InfoMesh views. Participants were asked about their impressions of the underlying ideas, the illustrated views, and the perceived function and use of InfoMesh.

Segment 3 detailed 'Aran' and several of his activities that were tracked through InfoMesh views. Participants explored the matching views presented by the desktop and PDA prototypes, interpreting and interacting with them. The evaluator requested participants to perform several simple interactions during these exploratory tasks. At the end of the tasks, participants were asked about their initial reactions, their thoughts on view interaction and use, and their understanding of the conceptual elements, view content, functionality and tools.

Segment 4 revolved around several small assessment tasks that participants performed using InfoMesh. These tasks included using the InfoMesh menu bar, toolbar or FlexTools to annotate view items and the view space, create a new contextual view for an existing view (such as creating a social view for an existing activity), and switching between contextual views for an activity. Post-task questions focussed on participant views on InfoMesh use for activity work and their experience of dynamic views, their personalised content and the option of having multiple contextual perspectives on the information space that can be queried and archived.

In segment 5, participants compared Aran's InfoMesh views with hierarchical folder representations of the same information. They then voiced their views on the respective strengths and weaknesses of the two systems, and their views on InfoMesh use for their own activities alongside existing systems of information visualisation and access.

Segment 6 finished the study with a final questionnaire that asked participants about their views on InfoMesh views, interaction and use on the whole, and its strengths and weaknesses.

USER STUDY ENVIRONMENT AND EQUIPMENT

Following the same reasoning as used in the first study, a usability lab was used to evaluate InfoMesh interaction and use, as this environment sufficiently recreated the fixed location use of InfoMesh for the tasks carried out. For studying real-world use of InfoMesh, especially the interplay in the use of multiple fixed and portable devices, the selected environment falls short. A thorough evaluation obligates a field study that takes into account an extended time period and the interplay of multiple personal devices.

The study made use of a personal computer running Windows XP Pro and a PDA running Windows Mobile 5 (a Dell Axim X51 in this case), both of which ran their respective versions of InfoMesh. The InfoMesh *Composer* and *Presenter* applications, their supporting environments and application data were installed on these two devices. The personal computer also provided participants with access to the Internet using Internet Explorer 6 or above.

Physical artefacts and support material used in the study included audio recording software, InfoMesh desktop and PDA prototypes, a system user guide, persona

and activity scenario descriptions, a participant workbook with tasks and questionnaires, as well as evaluator interaction and observation guides.

PROCEDURES

Procedures for the second study closely mirrored the first. Participants were greeted and acquainted with the study environment, before they read a consent form and the bill of rights. The evaluator then described the study purpose and tasks, and explained that an audio recording would be made of the study session. Once participants consented to the study, they were given a user guide to InfoMesh and a participant workbook.

At the onset of the study, participants were asked to answer a background questionnaire. They then read through the user guide sections, which described Pervasive Personal Information Spaces and the InfoMesh system, before answering a brief questionnaire.

Participants were subsequently introduced to the persona 'Aran', his activities and corresponding InfoMesh views through scenario descriptions in the user guide. The evaluator encouraged participants to view, interpret and interact with Aran's InfoMesh visualisations on the personal computer and PDA through a series of exploratory, assessment and comparative tasks. These tasks were interspersed by questionnaires and discussions, which helped in gauging their understanding and perceptions of InfoMesh views and interaction. Questions and discussions also touched upon personal attitudes and preferences towards InfoMesh use, usefulness and appropriateness, by inquiring into participant activities and information behaviour in light of InfoMesh features and Pervasive Personal Information Spaces.

At the end of the study, participants answered a final questionnaire that broadly considered their impressions on InfoMesh and its underlying concepts. They were then thanked for taking part in the study and rewarded for their time.

The evaluator/observer was present with the participants all through the study sessions, and performed several tasks, which include:

- Explaining all the tasks of the study to the participants, and encouraging them to freely give their comments and share their ideas, and ask questions.

- Recording comments, ideas, and answers to questions; timing tasks; and setting up the InfoMesh prototypes and folder views for user interaction as appropriate for the tasks.
- Participating in the task and questionnaire discussions.

DATA COLLECTION AND EVALUATION MEASURES

Similar to the first study, the following quantitative and qualitative data was collected to evaluate the InfoMesh prototypes and the underlying conceptual model:

- Details on participant understanding of the concepts underlying the InfoMesh prototypes and the views they provide.
- Details of how participants explored and interpreted the views (as pertaining to the persona 'Aran', his activity scenarios and activity snaps) provided by the desktop and PDA prototypes.
- Details on participant interaction with the desktop and PDA prototypes, in both the exploratory tasks (interacting with InfoMesh views of Aran's activities) and assessment tasks (creating and manipulating views).
- All difficulties, misconceptions and errors encountered by the participants during the study. (These will be classified, and the possible sources of these problems will also be determined and noted.)
- Commentary on how participants compared views of Aran's documents as provided by InfoMesh and as provided by current hierarchical folder views.
- Participant views on InfoMesh and its use, especially in providing access to information and supporting high-level activities and work context.

The data was derived and compiled from 1) observations of how the participants completed the tasks and how they used and interacted with the prototypes, and 2) participant comments and questions, answers to questionnaires and discussions with the evaluator/observer.

7.2.3 STUDY ANALYSIS AND DISCUSSION

The observations and user feedback from the second study deepen and expand on the insight provided by the first study on InfoMesh views, interaction and use:

- The background questionnaire gave information about participant devices and information interaction, focusing specifically on recent activities and related

contextual details. These activity descriptions and details provided insight into participant information behaviour as pertaining to InfoMesh use and were accordingly revisited through the study.

- The brief introduction to Pervasive Personal Information Spaces and InfoMesh through the user guide allowed participants to indicate their early perceptions and impressions of the concepts and the system. They especially left room for participants to expand on the descriptions by hypothesising how such systems would work.
- Exploratory tasks using the InfoMesh prototypes supported participant exploration of and interaction with InfoMesh views according to specific activity snaps for the persona ‘Aran’. The prototypes encouraged participants to share their thoughts and opinions on InfoMesh, and helped discern their ability to understand and interpret InfoMesh views and view content. Participants exploration and comments also pointed out view appropriateness, usage, interaction and usability issues.
- Assessment tasks brought forward further perceptions on InfoMesh concepts, interaction and use, especially in relation to flexible views and associative tools.
- A comparative task that considered InfoMesh views and hierarchical folders views for Aran’s work once again looked at user perspectives on the two systems, their similarity, complementary features and usefulness.
- The end of study questionnaire and final discussions highlighted user perceptions of Pervasive Personal Information Spaces, the strengths and weaknesses of InfoMesh, and their application in the real world for providing ubiquitous access to information.

BACKGROUND QUESTIONNAIRE

Question: How do users make use of their devices to support their activity work?
What are the contextual details that make up their work?

The background questionnaire considered participant devices and activities, before asking about one or two specific recent activities and their details. These details included information usage, work context, device usage, and contextual information relationships that participants denoted explicitly.

Device usage

Participants used a variety of personal devices. Alongside the use of cell phones, participants interacted regularly with two to four devices each, which included PC and Mac desktops (at home or university) and laptops, Internet tablets, PDAs and smart-phones. Laptops were mostly designated for use at home or university, though they were used on trips away and occasionally carried between locations of use.

Participants stored a wide range of multi-media information on these devices to support their activities. There were common and personal aspects to how participants designated device use, how they distributed work across devices, how they synchronised and archived information, and what activities they engaged in.

Participants sometimes designated work and personal devices, which largely supported either their study or their leisure activities based on device capability, preference or location. So devices at university were more frequently designated as work computers, with home computers or laptops used for different personal activities. However other participants either preferred one device for all their study and personal activities, or utilised all of their devices for their study and personal work to different extents. Extrapolating this information with respect to professional work, individuals would show preferences that fell in the spectrum between keeping work activities bound to a designated device (as at their workplace) and carrying out those same activities on any of their personal devices as the situation called for (e.g. devices at home or portable devices).

Device designation or lack of it affected distribution of information across personal devices. According to each participant, some activities were unique to specific devices (e.g. gaming, internet banking, teaching support), whereas other activities and corresponding information overlapped (e.g. music, research literature). This has consequences for InfoMesh, where participants would benefit from synchronisation options that can be selected or de-selected according to activities or areas of interest. InfoMesh overviews and device-based context views would also aptly show the resulting personalised distribution of work in the information space and across devices.

Participants backed up select information on another device or through email (e.g. select activities such as research work, or specific information categories or media such as photos, email or even most of a device's content). Participants indicated

that they did not back up their information to the extent or as often as they would wish to. Consequently they simply focussed on their most important activities or media. Often the backups had inconsistencies, which rendered future backups harder.

Broadly, information located on a device was related to various activities, such as study (e.g. giving presentations, writing an article), leisure or hobby (e.g. travel planning, researching dancing lessons, managing the start of the season for a hockey club) and administrative (e.g. online banking, shopping) activities. Large swathes of information also fell into several media categories that were identified separately as simply music, photos and video games for example. Participant comments indicated that information they interacted with (especially online) was at times of long-term importance (e.g. articles, financial statements) and at other times quite ephemeral (e.g. bus timetables, forums). The impact here on InfoMesh is to support users in incorporating meaningful browsing information related to their activities, while excluding information of fleeting interest.

A close-up of user activities

Participants described some recent computer-supported activities, indicating the amount and type of information used for these activities, contextual details such as conversations or emails with people and various annotations, the role of their devices in supporting these activities. Participants also stated how they related contextual details to their work to remember them later (e.g. organisational systems or software, paper or digital notes, reminders and memory). All these details exposed something of participant activity practices, work contexts and information behaviour that provided insight into each participant's preferential view of InfoMesh use and usefulness. Two illustrative examples follow:

Hockey season preparation: The activity involves getting everything ready for the start of a new hockey season for a hockey club, including preparing information for hockey trials, player lists, and registration documents, which occurs over a period of several weeks. Activity documentation includes player lists in different formats, emails and official document and spreadsheet forms. There are regular deadlines to meet. Information is gathered on the hockey turf, while the forms are filled out with remaining detail at home. Contacts include players, team managers and the central hockey organisation. Communications deal with getting updated

information, new registrations and dealing with committee requests. Personal devices are essentially used to find, store, communicate and formalise information. This activity is specifically carried out using the laptop. The participant stores the information in a hockey folder with sub-folders for each year (with further folders for players, teams etc.), which provides some contextual information (information relationships and categories). She tries to remember all other information, which she finds increasingly difficult when working on many different activities.

Preparing and giving a presentation: This activity revolves around preparing and giving a presentation on a visit to another university, by bringing together research documents and creating a presentation over the course of a few days. The visit was organised in the prior weeks, through emails about the presentation as well as transportation options. Activity documentation included research documents, presentation files, images, emails and online calendar entries. The participant mainly carried out work on her laptop, which was to travel with her. Contacts for the activity included her supervisor, who discussed content and provided suggestions, a lecturer at the visited university who gave information on presentation content and length requirements, and a friend who provided feedback on the presentation material. The participant kept track of contextual information in part through Google calendar and email, and in part by memory.

Other activities mentioned by participants included carrying out a user study, travel planning, writing a thesis, preparing a course and so on. All discussions illustrated the unique and personal aspects of each activity, with respect to the participant, the activity content as well as its context. The work context formed the full picture of the activity in their recall and portrayal of activity content, interaction and goals. In tracking contextual information (e.g. time, goals, notes), participants employed a variety of techniques including folder organisations (e.g. sub-folders for each year), paper diaries, email (e.g. an email tracking each activity in a separate email folder), online calendars, online wikis that were difficult to keep up to date, text files with notes and idea lists (e.g. progress files for every month). Still, most of the contextual details were committed to memory for future recall. Participants considered physical tracking using the above techniques laborious, time-consuming and incomplete. They felt that

remembering details added strain when juggling multiple activities, stating that some things were also naturally forgotten.

INTRODUCTION TO PERVASIVE PERSONAL INFORMATION SPACES AND INFO_MESH

Question: How well and easily can users understand the concepts introduced by InfoMesh?

The user guide acquainted participants with the concept of Pervasive Personal Information Spaces as well as the InfoMesh system. The guide left participants room to form impressions, describe the ideas as they understood them, and interpret InfoMesh workings and use.

Participant impressions were on the whole positive, describing a need or desire to have a visual tool that provides access to all information and an ability to tie things together. The fear one participant expressed was with losing information, due to a system breakdown or theft, and the need for creating easy backups.

Personal preferences motivated interest in specific aspects of the underlying concepts. Several participants voiced their preference for a visual depiction of information as well as the use of personal annotations. Among the participants, individuals leaned towards specific contexts that they personally felt were most useful to them: *“Location and time for me personally would be good for sorting my data”*, *“Personally would relate information to where it happened... that’s quite easy”* and *“For quite a while I have been wishing to have a tool ... I’m quite a visual person, spatial thinking, so I’ve always wanted to have something where I can group items, colour code them and put annotations next to them ... this looks quite exciting”*.

Participants largely perceived InfoMesh as *“organising information in a visual way”* using contexts like location, time and people. Most of the participants separated the underlying concepts into the separate ideas, one of *“having a space or collection of documents, independent from actual device”* and the other of having a *“visualisation to help you to re-find & make sense ... of information you’ve used before and new information”*. They also grasped that the set-up aims to *“stop the fragmentation of all the little things you’re working on, and bring it together in one place, so that it makes it easy to reference and easy to see what*

you're working on". Additionally they understood that the system "*supports multiple ways of accessing information*" by automatically gathering and integrating information.

Some elements were unclear at the beginning. Some participants wondered how the information integration and synchronisation between devices would work and how non-networked computers would be supported. One participant questioned whether the system would integrate well with everything else on the devices to especially track emails and web browsing in detail as well. Another participant was interested to know whether the system embraced a form of version control when depicting work over time, especially when dealing with collaborative work.

When considering the ideas behind Pervasive Personal Information Spaces and InfoMesh, users felt that the "*general idea seems quite good*" and that it seemed "*useful*" especially in relation to having visual and ubiquitous access to their information. Example participant comments included statements such as: "*I would need this*", "*context will give me more information of what I was looking at*" and "*sounds very handy to have one place to go to, to see the organisation of all the different things that you've been working on over time*".

Participants indicated that time allowed them to see what they were working on at any given stage and gave them an overview of their work. Social views on the other hand gave them a handle on their collaborative work, detailing "*what are the shared documents, who's been working on what and when*". They also felt that the ideas took out the guess work in remembering which information was stored on what device, while at the same time providing access to information from any device when faced with sudden queries. Another participant opined that InfoMesh made it "*easy for other people to see what you've been working on as well ... if anyone was to look at my computer they would not have any clue as to what I have been working on at any given stage, whereas if they saw a screen [InfoMesh visualisation] like that they could see what you've been working on at the time.*" This idea correlates well with support in InfoMesh for sharing views. Visual representation of information usage and context allows other people to interpret activity as well as follow information trails shared by one another.

EXPLORATORY TASKS: INFO MESH DESKTOP AND PDA PROTOTYPE VISUALISATIONS

Question: How well and easily can users understand and interpret the context-based flexible views presented by InfoMesh on the information space? What are some of the usability issues in the current InfoMesh prototypes?

Participants read the description of the persona ‘Aran’, a general scenario of his use of InfoMesh as well as several activity scenarios (for the familiar ‘Art Inspiration’, ‘World Cinema’ and ‘Writer’s Corner’ activities explored in the InfoMesh walkthrough in chapter 5). As participants read through these scenarios, they explored and interacted with the matching visualisations on the InfoMesh desktop and PDA prototypes.

These exploratory tasks helped discern participant reactions and preferences, understanding and interpretation of InfoMesh views. As the prototypes supported far more interaction than in the previous study, participants were also able to play around with the functionality and comment on InfoMesh interaction and use. Their interaction and comments narrowed down some further usability issues.

InfoMesh views and interaction

In this second study, the views targeted were limited to the selected visualisations and design elements from the previous study that were fleshed out with further detail and functionality. Participants answered a variety of interactive questions during their exploration. These questions asked about what they noticed about the view, what kind of information the view gave, how they interpreted the view content and view elements, how they would use the view to access or track information, and how they would annotate the view. Questions further probed into their personal preferences as to annotations, ideas and usefulness, especially in relation to their own information behaviour. Their comments and perspectives largely supplement the findings from the first study. They are therefore presented here in summarised form for each type of InfoMesh view.

Overviews: Participants looked at Aran’s InfoMesh overview, work view and notice board. These views were described as part of a scenario describing Aran’s use of InfoMesh.

A) Understanding and interpretation: Similar to the observations in the first study, participants followed the overview visualisation easily, separating out the top-timeline and bottom-workspace delineation. They recognised the timeline as providing “*an overview of what he’s [Aran] working on*” with a past-present-future depiction, where the histograms indicated activity duration and interaction intensity. They understood that the view also provided a summary of several other activities, namely more recent ones, with the last accessed documents (e.g. “*Art Inspiration [view pocket]...five documents... recent list of documents that have been accessed*” and “*This space [view pockets area] kind of tells you what you have been doing recently... if you want to access something I was working on yesterday, I’d expect to find it there*”). Participants discerned that Aran had classified related activities under similar colours. This colour coding of activities on the timeline correlated with the view pockets in the view workspace.

Participants strongly felt that the view supported interpretation of their various activities, next to providing an overview of their ongoing work. The timeline allowed them to see:

- an overview of their work, showing past and current work, indicating which activities they were up to (e.g. “*I can see where I am right now. I can see which kind of projects Aran has worked on recently... usually the projects he would have done recently, most of them are still relevant at the moment, so it might also serve as a reminder of ok, what is it that I actually need to do today*”, “*It shows you when you have not done a certain activity for a long time... you might have forgotten about a project*”).
- activity information such as time, duration and status (e.g. past, current or ongoing activity) (e.g. “*it [the activity Art Inspiration] was obviously done through the end of Jan to the end of Feb*” and “*...the art and artists one seems to be pretty much ongoing*”).
- the interaction frequency for activities, patterns in activity work and other salient pieces of information that can be used to interpret or compare activity work (“*I can also see little bursts of activity for the projects, so for example it looks like the writing for the Scale magazine... seems to occur in bursts always at the beginning of the month, so probably there is a deadline somewhere in the middle of the month*”, “*so it looks that at certain time of the month Scale [the e-zine Aran writes for] comes out*”, “*it might give an idea about which*

activities are using up a lot of time”, “timeline shows amount of time spent on each day on different tasks”, and “It shows you when you have not done a certain activity for a long time... you might have forgotten about a project”).

In their interaction with other views over the course of the study, participants often preferred returning to the overview, treating it as a launch pad in InfoMesh for visiting other recent activities. In their brief exploration of the InfoMesh work view, participants followed the idea of using the view when working on several activities at the same time. They largely saw the notice board as a to-do list with space for annotations, which shared similarities to the desktop interface with none of the specific organisation seen in the other InfoMesh views.

B) Use and interaction: Participants viewed the overview visualisation as a starting point for (re)finding information (e.g. *“it’s a starting point for finding my data”*), similar to a file manager except geared toward their activities and most recent work. They felt the timeline allows you track and revisit work based on natural memory of when an activity was carried out relative to time and other activities (e.g. *“I think it’s good to give you an overview of what you are working on as a whole, all the different projects that you’re working and just to see your progress on those projects over time”, “you remember that something was several years ago... the topic and the time, and you can kind of pinpoint it... you click on one of the histograms... and see the documents around that time [for that activity]”* and *“From the timeline point of view, if I know that 6 months ago I did a lot of work on a particular thing and something I want to look at is part of that ... I would expect to find a peak on the timeline and maybe use that to access it and sort of move through time to see the view”*). Participants felt that this came in handy especially when retrieving specific documents based on contextual cues, supporting information orienteering behaviour (e.g. *“I might... scroll back in time... as I said, for the course I re-used some pictures I’d already used in previous talks... I remember this particular picture and want to use it in my talk, and I remember that I had it in a talk, then I would try to remember which particular talk it was...”*).

They also felt that the overview was useful to both track and see their progress over time (*“I think it’s good to give you an overview of what you are working on as a whole, all the different projects that you’re working and just to see your*

progress on those projects over time”) as well act as a reminder of where they were in their work (*“I think for me, it would mostly be the way it’s shown right now, where it shows the last few months... which projects am I currently working on and as a reminder”*).

C) General reactions and preferences: Participants found the views (overview, work view and notice board) inviting and encouraging of user exploration (e.g. *“it [a specific website] was all text and I can’t find my information there at all ...when I saw yours, with the four squares and the colours, it is more pronounced that this is one thing, that is another... it invites me to explore it”*). They all appreciated an overview timeline showing their work over time. View elements they liked included incorporating colours to indicate different related activities, seeing activity interaction frequencies, and zooming in and out (especially on the timeline) to review and access information.

The task highlighted a number of issues and elicited some participant suggestions. Initially, the overview provided pockets for all recent views, rather than recent activities, which confused participants as the same activity might be present more than once (e.g. as an activity view and a map view), which was therefore changed after the study. Similarly naming schemes for the views were a little confusing (such as using the name TimeSpace view for the current Activity view, even though it was referred to in relation to activities). As a consequence the naming scheme for InfoMesh views was simplified and streamlined more.

One participant indicated that the timeline histograms were a little small for accurately clicking on a specific part (e.g. to visit the view at the corresponding time), though she felt that zooming in on the timeline made this much easier. Another indicated that she would appreciate being able to zoom in and out on the timeline using the mouse scroll wheel.

A suggestion was made to link markers on the notice board to email objects or particular activities to make them more active and useful. One participant further showed interest in having classifiers for items in the work view for their categorisation into activity pockets, which would add some level of application intelligence to InfoMesh and reduce effort when working on multiple activities simultaneously.

Activity View: Participants interacted with the activity view for “Art Inspiration”.

A) Understanding and interpretation: Once again, participants followed much of the meaning and use of the view elements and content after exploring the view briefly (e.g. using the timeline lens to navigate through the activity space, moving items on the view and adding annotations and markers). They identified the most significant elements first: the timeline at the top, which showed a zoomed out version of the daily view on the bottom containing time delineations, documents and notes. They thought aloud about the significance of various view elements, and interpreted them readily according to Aran’s activity space and documents (e.g. *“Green [colour-coded documents]... seems to be some literature stuff... yellow... I think it’s work of art, visual art... a yellow star [marker]? what does it mean? ... drawing attention? colour symbolises grouping... some I can identify, some I can’t”* and *“work on the art inspiration project over time... it’s obviously different streams of work that have been done”*).

The annotations panel displaying item annotations and a holding area largely made sense, though the term ‘holding area’ was confusing to a couple of participants. They felt that both annotations and a holding area for important items would be very useful depending on each user’s work style.

As with other InfoMesh views, the activity view encouraged exploration and participants used many of the visual and contextual cues presented by the view to interpret Aran’s activity space. This ability to interpret the InfoMesh activity space or information trail from the various cues is of importance when sharing views with others and when returning to an older, archived activity. For Aran’s activity, participants were able to interpret when work was done, what was looked at, what ideas were noted down and who was contacted from the documents, notes and markers on Aran’s view (e.g. *“He’s been drawing pictures... writing about them and getting feedback from other people perhaps... and looking up inspiration for it, some web pages here... deciding on what he’s going to work on...”*).

Participants grasped that the activity view groups information that is accessed together with notes and information relationships intact (e.g. *“[shows] all the things that have been worked on on a particular date and any sort of additional information I want recorded about it”*, *“it shows me which files Aran has worked with, roughly at which time”* and *“[gives] relationships between documents*

accessed together”). They felt that this information allowed them to locate and relate documents according to time and their work (e.g. *“It’s detailed enough to see things like morning, midday, afternoon things like that, which also means that it’s easy, if I know that there was a web site I looked at when I also looked at some other file, then it’s easy to correlate it time-wise to find the other document I’m looking for”* and *“It might also... answer questions about when did I first hear about this.”*).

B) Use and interaction: Participants deemed activity views useful in their work for several reasons. They suggested that activity views allowed users to track their work over time and similarly back track to review their actual work and the direction of work: *“[use for] some sort of projects that you want to track and be able to back track, to see where you have come from and what you’re going to”* and *“One could back over one’s work... maybe you’ve overlooked something, some interesting aspect. You had this idea this day, but perhaps you forgot it...”*. One example given was tracking web site visits, with the change in directions and focus of web searches.

Participants felt that the view supported work resumption, as the view presents all the documents for the activity together alongside notes, within the context of time (e.g. *“When you start a project... you have all the documents that add to the task, but you also know when you found them. The time context might have meaning as well, cause your work develops over time...”*). They also expressed how contextual cues such as time and colour coded information relationships would aid retrieving information (e.g. *“So if I want to look at something that I’ve worked on two days before, I can just go to that, move to that space in time and get the information I want”* and *“Also the colour coding as well, so I can, if I don’t remember necessarily a particular date, I know I’ve worked on a lot of things from a particular topic, I can see from the overview [activity view timeline] by the colour coding”*).

Several participants specifically voiced how activity views would allow them to pull together different pieces of information in their activity space, especially through the various types of visual and textual annotations provided. One example given related to managing articles of interest, with key ideas entered as notes on the workspace or item annotations, colour indicating whether she had read the

article yet or not, and markers indicating actions that needed to be taken (e.g. getting a specific book from the library). Another example related back to a participant's own activity for preparing for the hockey season, where an activity view would track her documents with annotations and markers indicating details that were still missing and deadlines for the day. The general feeling was that the activity view provided a "*more appropriate way of viewing things over time*" than a time-ordered listing of documents, due to the depiction of information associations in time and the personalised annotations.

C) General reactions and preferences: Many interaction elements seemed natural to participants (such as panning workspaces, zooming in and out, using item pop-up menus and navigation buttons on the toolbar), especially once they were introduced to them. However, they did bring up some issues. One participant felt that having a separate overview timeline might be redundant, especially when you can zoom in and out of the workspace. Still, she felt that for long activities the timeline would be helpful. She also indicated that knowing where we are currently in the view relative to the entire activity space would be very useful to have (as for example indicated by a scrollbar's position in standard applications).

Participant preferences once again indicated individual differences in their information behaviour and interaction. Where most participants were very visual and felt colour-coding was a strong and useful element in InfoMesh views, another stated that she was "*terrible at colourising things*" and she would rather flag items as important on the workspace to remember certain items or actions. Similarly some participants felt that they would not use markers much, whereas others found them useful as reminders for notes, events or actions.

These preferences also have consequences for information retrieval, where different participants would use different contextual cues (such as information relationships and notes or otherwise time) for locating information in the activity space: "*For me mostly re-finding information based on ...ok I know that I looked at this web-site roughly at the same time I was working on whatever, so I go to the document that I do remember and then look at ok which web-sites did I look at just round then, so to re-find things... and maybe also for keeping track of when did I first think of this or become interested in this topic*".

Several usability issues and participant suggestions came to light during the task. The “open” option on the toolbar was not intuitive for many participants. It follows the standard ‘open folder’ representation, which many participants did not immediately associate with opening an activity or view, and rather associated with opening a file. Another option would be to have a drop down box on the toolbar listing a number of recent user activities to select from, with a ‘browse’ button for selecting from a list of all activities. Similarly one participant indicated that swapping view types (offered in the FlexTools panels) and also flagging items for importance (offered by the popup menu) may be better placed on the toolbar as well. They would then be just that much quicker to access, especially when the functions are used regularly.

One participant brought up the issue of having a wide colour palette, which makes it difficult remember and re-select the exact shades used for coding items on the view. One option would be to provide a simpler colour palette of sufficient but distinct colours for use instead. An added colour legend was deemed useful for each activity, especially when returning to archived work. This can be achieved by generating a colour legend for each activity as part of a FlexTools panel, where users can add a note or keywords to each colour.

Some other small changes would include adding shortcuts on the toolbar for the overview and work view alongside the one for the notice board, presenting item annotations as item ‘ToolTips’, and allowing the user to print a summary of item annotations for a view. The timeline lens at times also played up by making some random movements, which needs to be corrected. Marker positioning can be improved by supporting a drag and drop functionality, rather than providing the simple automated placement at the centre of the user’s view. One participant mentioned changes to the mouse cursor indicating the active view elements that can be used for navigation or further information, such as view pocket title bars, histograms and view items. Also, another participant preferred having the option to multi-select items for colour coding and annotations.

Finally one participant brought up the issue of privacy with respect to other people seeing what someone has been looking at in detail with time information. Due to the brief nature of the study, the participant was not aware that the system requires user verification and that view detail can be customised upon sharing. Long-term

use of InfoMesh would shed more light on what privacy issues might arise and how they may be handled.

Map View: Participants explored Aran's map view for "World Cinema".

A) Understanding and interpretation: The map view was readily understood as organising and displaying information according to locations relevant to the activity's information items (e.g. *"It's information structured on top of some kind of a map"* and *"It's tied to regions of the world. There are web-sites or documents associated with a particular area."*). Participants said that those same locations provided a straightforward way to get to information (e.g. *"It's easy to look at a map and go to a specific spot..."*). They also noted that the view continued to provide similar features to the other views, i.e. colour coding, annotations, and navigation features such as panning and zooming.

The most interesting observation was that the view invited instantaneous exploration, comprehension and interpretation of the information presented. All participants were engrossed in taking in the view content, exploring the places on the map and voluntarily remarking on the information there and the location associations (e.g. *"That's nice to explore"* and *"Well... it's more topic related... I like the view, because I started thinking about the topic immediately, rather than how do I find anything. It works."*). Participants felt that the view implicitly said much about the underlying activity and information items. In this case, the task showed that context (such as location through maps) allowed transparency in retrieving and interpreting information, even if that information was not directly gathered or generated by the user looking at the information.

Participants interpreted information presented by the view readily and were able to use the underlying map to retrieve information (e.g. *"I'm able to just go to some Australian movie sites I went to before by just using the map to navigate to the location and the site"* and *"to quickly find them [store sites] if you want to have [for example] a Bollywood movie"*). They implied that where a specific context is most relevant to the activity's information, that the same context becomes an easy point of referral for retrieving information. Participants were able to make interesting inferences from the view about Aran's activity (e.g. *"[Aran can] realise he doesn't have any shops that have African movies or South American or Alaskan..."*).

In the study, the visual nature of presenting context and information showed that making sense of information, associative or contextual retrieval of information and information sharing could occur in new and at times easier ways than when the same information is presented as a list. For example, when sharing a view like “World Cinema”, the map placement of information items explains much about the items. These items can consequently be easily interpreted and acted on by a user, even if he or she did not create the view or carry out the initial activity.

B) Use and interaction: Participants views on the use of map views varied greatly, both with individual preferences and unique location-oriented activities. Two participants indicated that a location-oriented view might not be useful to them on a day to day basis, though they liked the view’s presentation of information. One of the two participants stated that she did not deal with much information that was related to locations specifically (virtual or real), but felt that the view would be useful for a number of activities (*“I can imagine lots of uses for it, it’s just that the way I deal with documents doesn’t seem to work out”*).

Otherwise, participants provided diverse examples of use drawn from their own needs, experiences and activities. One participant felt that building maps would be more obviously useful to her. She had mentioned the difficulty in filing and locating isolated pieces information earlier (such as information on small numbers of cattle kept at the home farm), as they could not be easily classified or retrieved through a hierarchy of files. However, even isolated pieces of information may form relationships together within a specific context: *“Thinking very literally in terms of a geographical map is sort of less obvious than... a map of a house or something like that... my miscellaneous things, I could have a map of the house and the farm, and the cow information in the paddock... attached to the cow, I also have like sticky notes with jobs that I have to do around the house and the farm (like fix water trough in paddock) ... be sort of geographically positioned ... if I want to do some work and well the cows are in this paddock, that paddock is free so what jobs need doing there, then that’s a nice little list of things that need to be done”*. So here information is associated directly to locations and objects drawn on a custom map, retaining meaning and increasing retrievability due to the context association. Other examples in the varied set highlighted the use of

customised maps and context-associations for visualising, tracking and comparing location-oriented information:

- Travel: Using maps to track places to visit (e.g. holidays or conferences) and sites of interest, as well as plan travel accommodation and activities (e.g. *“a fictional map ... a LOTR map... and keep track of which locations I have actually seen that were a set location ... I could easily do that”*).
- Social: Tracking people or offices (e.g. colleagues, friends, departments or office branches) and associated information or work.
- Virtual: Using custom virtual maps and the various annotations for classifying information or brainstorming work.
- Authorship: Carrying out world-building for novels and associating relevant events, people and so on with map locations (e.g. *“If I were writing a book, then I think it would be very very useful, to actually make sure I can see what happens there [referring to different locations of the book’s world]”*).
- Context-based action: Using location context to indicate tasks or work that needs to be done. A map would add visual, contextual triggers to the standard textual to-do list and can be easy to review and update. An example that followed from the map of the house and farm included associating jobs that need doing with different areas of a map.
- Real-estate: A local map can be used to uniquely track the properties of interest to a buyer, when working with multiple real-estate web sites, queries and listed properties. Annotations, colour-coding and thumbnails would further clarify listings of interest. Switching to a temporal view also shows the changes over time geared toward the most recent listings of interest.

Though a map view’s use on a daily basis may be uncertain, participant interaction and detailed examples showed the need to consider and incorporate this context for visualising information (*“It’s certainly good [to] think about it”*). Contexts work very well together (e.g. time and location in the real estate or travel examples) and this task also highlighted that. One participant indicated that the map view loses the time aspect of the activity view and basically underlined the potential usefulness of view flexibility in providing multiple contextual views on the same information (*“It obviously loses the time effect that the other view had where you’re viewing things over a period... it’s not obvious how old any of these web-sites and how out of date they are”*). At the same time it also showed support

for the combination views explored in the design phase, which combined two contextual views (e.g. the small timeline overview from the activity view, with the map view as the workspace).

C) General reactions and preferences: By this task, the participants were comfortable with the interactive features in InfoMesh. They appreciated both the panning and zooming features, which felt natural for navigating map views.

As noticed before, participant preferences for the view were based on their own activities and whether these activities had a relevant location context or not. The personal associations underlying any activity tracked with a map view are important in making sense of information and context. Aran's 'World Cinema' map view does that for Aran, with wish lists, language and region based organisation. However, it was clear that the contextual visualisation would be easy to explore and interpret when shared with others, above the offerings of hierarchical lists of documents.

The task once again brought forward some usability issues and participant suggestions. InfoMesh performance was noticeably slower for the map view on the device used for the study. The task showed a need to improve the dialog for opening activities and views, which lists everything together for selection. An improvement would be to let users select an activity first from a list and then select the view they want to open as a separation option within the dialog box.

Smaller observations and suggestions included a single mouse click moving an item to the top for viewing it clearly, with a double click opening the document. Another participant suggested changing the default annotation for items to nothing, as a default value such as "No annotations" attracted unnecessary attention to the FlexTools panel when moving over an item. One participant also suggested having an option to assign tasks to information items, perhaps alongside annotations and markers, to indicate anything that needed to be done.

Observations showed that some sort of visual indicators alongside information items might be useful to indicate the presence of annotations, associated tasks or availability (in PDAs for example). However this idea needs to be explored, designed and evaluated to understand how it can be implemented and how helpful it may be.

Social View: Participants interacted with the social view for Aran's "Writer's Corner" activity before looking at its corresponding activity view as well.

A) Understanding and interpretation: All participants understood the social view as presenting documents according to the people authoring and sharing them (e.g. "*I see what it's for, I see that it's for organising the work flow between these people, that's clear immediately*" and "*How many documents one person has done... how many things they have reviewed*"). They also understood that when people were moved on the view, their documents moved with them. One participant pointed out that the view might become chaotic with larger groups of people, though zooming in and out and an appropriate zoom factor when first presenting the view would alleviate that.

The graphical representation of people, their documents and their relationships was liked and considered straightforward (e.g. "*I'm seeing a social network...*" and "*I quite like the connection between people with lines*"). However, how each participant interpreted the graphical representation and relationships differed somewhat at the beginning. Without an explanation, the perspective offered by the view could hold some ambiguity.

The social view provides a user-centric view of shared information, rather than focussing on finer details of collaborative work that indicate for example who edited a document last or how much of a document a person is responsible for. Most of the participants understood that documents alongside Aran's friends were authored by them and shared with Aran, and documents alongside the line connecting Aran with his friends are authored and shared by him. Others suggested other possibilities, especially with their personal preferences in mind. One participant for example preferred a social view to relate document distances on the view to their relevance to or the amount of work done by the people in the social network. She also preferred the connections between people in the network to show the direction of the workflow ("*I'm not completely sold on the idea of keeping what they are sharing down at the very end... When I see a line like that, [I] expect to see the direction of the work flow*").

At a higher level though, the view allowed participants to interpret and make inferences on "*the interaction between different people*" and what was shared for activities with a social component (e.g. "*He's connected with four people*", "*Who are the people that documented [the work]... how many documents I gave to*

someone”, and “*It’s all kind of interesting the positioning of things in relation to people... for example if I look at this between these two people here... see that there is some element of collaboration between these two people on this item*”).

B) Use and interaction: Participants focussed on practical questions that social activities raise when talking about uses for social views. They felt social views would answer these questions about who you have to contact for certain documents, what you need to discuss with someone, who authored or shared a particular document, and where documents came from or went to (“*For this kind of activity [an example given by the participant], it would actually be really useful to see this kind of ‘who did I share it with’ information as well*” and “*Knowing who’s done what and put together ... a map of where all the work has come from and where it’s going*”).

One example of use included utilising the view to remember material that needed discussing (“*if this was my supervisor [pointing to a contact on the view] and over time you have accumulated things you want to discuss with him, and can just go there and you look on the line between you and ... oh alright, there was this and this and this... then it would be really useful for I always forget over time*”).

Another example dealt with reviewing and managing documents sent in for a conference (“*...there it would have been quite helpful to have a way of seeing which document have I sent out to this person already.... ten presenters, sometimes it was difficult to keep track... here I could just use the colours or markers to say which of these documents have been approved or not...* ”).

Throughout the study, participant examples revealed how they perceived InfoMesh views as tracking user work. That is, the focus was not simply on specific documents or information items, but on the process, the activity, the contexts of time and people, all of which allowed them to interpret, infer and retrieve details about the work using more natural cues.

Several participants implied that interpretation of the social view would be heightened by combining the social view with timeline information, as explored in the InfoMesh design stage (“*how many things they have reviewed... [but] doesn’t tell you when you did this*” and “*Really neat to have it integrated with a timeline view*”). When participants switched to the activity view for the same ‘Writer’s Corner’ activity, their initial reaction was one of “*it’s removed the collaborative*

information here” and *“lost information about people”* which was disorienting at first. For example one participant stated that it was confusing at first as time didn’t seem to be the most important information for the activity. However she went on to state that it would be useful at times as she *“might want to see the order in which things happened”*. Participants felt that it was therefore beneficial to have several views on the same information (*“You can’t get all the information in one view, so it’s good to have the different types of views”*). An example of the use of the temporal view for a social activity extended the example on managing documents for a conference. The participant mentioned questions from presenters that she had answered previously, saying *“if I had had this kind of visualisation for the information I shared with the presenters, it would have been very easy to answer those questions”*. Another example revolved around purchasing real estate, where the time would supplement the location-based information: *“I can also imagine for the buying house activity, you might want to see things in the order wherever you looked at the houses but also the map view”*.

The task definitely showed participant preferences and liking for multiple views on the same information, views that combined several contextual views, as well as filter and query tools to filter out specific items when switching to a view (e.g. *“I might not want to see all documents in the timeline, select specific documents and say only show these”* and *“There might be moments where I would want to see more than one [context view] actually.”*).

C) General reactions and preferences: As with the previous tasks, participant interaction with Aran’s social view shed light on various preferences, issues and suggestions for improvement.

The social view presents shared information from the user’s perspective for personal social activities, rather than providing detailed collaboration support geared towards professional work. As such, it seeks to answer certain types of questions about someone’s activity. Though participants were largely positive about the view’s use in this way, two did wish the view to offer more support for collaborative work.

The first study showed a serious participant preference for a graphical presentation for shared information rather than simple information listings, which the second study underscored further. Much of the positive feedback from

participants related back to the graphical aspect of presenting contextual information about their work, as it supported implicit understanding and interpretation. Participants further expressed an interest in using images such as web-based avatars for representing people in their groups (currently the view is based on adding photos or image placeholders).

The pilot study session exposed an important issue for views in InfoMesh. Initially, the social view displayed an array of visual notes and markers shared by all contextual views for the activity. These notes and markers annotated the work over time in the activity view. In the social view, they lost their meaning and made the view therefore appear chaotic to the participant. This leads to the notion that view notes and markers may need to be kept separate for different contextual views for the same activity, even if queries take all notes and markers for an activity into consideration.

As mentioned before, the graphical representation for a social view had some ambiguity. Once understood, some participants still showed a preference for a different illustration of information sharing and relationships. This observation underlines the unique perspectives and information behaviour in different users. The underlying meaning of a view like the social view must be adaptable to the user to truly support personalised visualisations of information. A social view can be presented in a myriad of ways graphically, using perhaps two directional arrows for indicating document sharing and associated filters, which was preferred by one participant. Each of the design possibilities begs exploration and study. Participant interaction with Aran's 'Writer's Corner' however showed the value of having a social view in the first place for visualising and tracking social sharing of information.

PDA views: Participants interacted with PDA views that corresponded with the various views for Aran's work explored on the main device.

Participants were aware that currently InfoMesh provided only limited support and interactivity on PDAs. Still participant opinion was positive about InfoMesh providing a similar interface to visualise and review their information on all personal devices, including PDAs.

Overall, participant impression was that the views on the PDA made all the user's information accessible in a consistent way to the views on desktop or laptop. Of

especial note here was the idea that the user's information was available wherever they happened to be (*"If you are out and about, you've got access to all your information in the same way, so you've got a consistent view"*). Consequently, several participants felt that the InfoMesh views on the PDA would be useful when visiting places or meeting with people to refer back to information. One participant referred back to the example of using the social view to discuss specific items with her supervisor. The PDA would help her identify the relevant information during her meeting. Another participant felt that the PDA views would be theoretically useful perhaps for examples similar to tracking her work around the house and farm using the map view. However, practically a PDA was not generally that useful to her (especially if she's working outside and the PDA falls or gets misplaced). She currently simply uses post-its stuck to her car keys. Participants largely felt that the desktop carried a lot more information than the PDA views, which was thought to make the latter clear for its size (*"First impression of that interface is that ... if I compare to the desktop, there was a lot of information and here... it's less information at a time, it seems more clear to me"*). They easily adjusted to the zooming and scrolling capabilities. They used the overview as a launch pad, returning to it to open the views for the various activities.

Participant interaction and comments did emphasise some issues and suggestions for improvement. There was a little confusion about the view name abbreviations on the PDA (e.g. MV for map view) that were included in the view and activity titles (e.g. "MV – World Cinema") for keeping these brief. With regards to the zoom features, one participant felt that the PDA views should indicate their current zoom mode and have an additional zoom level of 150%, while forgoing the 25% zoom level (as the latter was considered too small for some views to be useful). Another participant suggested allowing users to highlight an area to automatically zoom into that area, and opening all views at a lower zoom level to first provide an overview.

Participant perspectives and experience of InfoMesh

At the end of the exploratory tasks, participants responded to several questions on their experience with InfoMesh as a whole. They considered InfoMesh views and their appropriateness, view content and information relationships, user interaction,

use and usefulness for both the desktop and PDA prototypes. Their thoughts and perspectives build on the information gleaned from the first study, and help verify the strengths of InfoMesh in its current implementation and ascertain the areas that need further work.

Overall, participant views and reactions were positive. They indicated that the views looked good and useful (e.g. *“the visualisations looked good”* and *“Initial reaction... looks useful... I need time to use it...”*). They further felt that automated information transfers and work tracking in InfoMesh was *“quite handy”*, offering a solution for keeping the information on all their devices synchronised. Several participants specifically said that they liked having access to multiple richly annotated views on activities, ordered according to contexts like time, people and location (*“Ordering by time and location a good concept”* and *“It has a rich functionality with annotations and additional markers”*). Participants also said that InfoMesh was largely clear and easy to understand after the initial exploration (*“Didn’t immediately know what works how. Then you quickly get to know the view. I now know it quite well.”*). Two participants specifically wanted to use it in daily life to explore it more and determine how they would use it and what their experience of the use would be.

Participants on the whole liked the context-based views offered by InfoMesh, and appreciated the overview provided of their work over time. They felt that views presenting their work according to time, locations and people matched how people naturally relate or perceive information (*“Good idea to have all three aspects... time... people... and locality”* and *“The three views are fine... I like it... [they are] concepts I use to mentally organise data”*). One participant explained that the contexts used with views are not for organising and presenting information alone, but that the contexts are useful to search for things as well. The work view also garnered some interest, as it allowed working on multiple activities at once and afforded users the means to discard uninteresting items easily.

Participants wondered about certain issues such as remembering what the colour coding might mean when returning to an activity long past or how to present a large social group within a view. They however felt that InfoMesh provided a good initial start into matching work with natural contexts. Organising and presenting information through all of the different views in one application was

considered a strength, because of the interconnectedness and flexibility it offered (“*Nice to have it all in one program*”). Currently, InfoMesh seeks to complement hierarchical folder listings of information. One participant suggested adding a textual listing of information to InfoMesh to more directly complement the views.

All participants liked navigating and interacting with InfoMesh by panning and zooming. The interaction felt natural with respect to the contexts, like time and location, presented through the views (“*Interaction is fairly intuitive*”, “*Panning ... really like it... feels natural*” and “*The walking in time... I also liked that and [through] the space... on the map*”). Participants felt that incorporating FlexTools into InfoMesh alongside the different modes of interaction and navigation helped bring together many different capabilities such as making and reviewing annotations (“*Good way to get a lot of dense information in*”).

Some participants said that zooming functionality required getting used to initially, and may need to be supplemented with a way of seeing where you are within the activity space and specified options of jumping back and forward in time. As already discussed, some functions were considered to be more useful as toolbar options than as FlexTools or popup menu options.

Views on InfoMesh use and usefulness varied. Participants liked having the ability to contextually visualise their work using multiple views and annotations. Several participants mentioned how InfoMesh contexts provided a softer, relative picture of information, compared to the hierarchical folder system. They considered the visual and contextual presentation to be more appropriate for conveying work over time, in relation to people and places (“*The one [activity view] gives you a more appropriate way of seeing information across time rather than just as a list*”). This allowed them, for example, to better interpret the changes to their work and share information with others (e.g. “*The timeline is really good for tasks that occur over space, where the purpose of the task is itself shifting*”). The ability to use custom maps (including conceptual or building maps) for a map view also was considered useful in personalising work and information. The anywhere-anytime access through all personal devices was furthermore considered quite useful to reduce lost opportunities for sharing or discussing information and ease the effort of ‘hunting’ around for files.

Opinions on the practical use of the different views were however affected by personal preferences and information-interaction behaviour. Some felt they would use the activity view more and use the map view rarely, whereas others held the opposite opinion. Naturally, the views were considered to be most useful practically where InfoMesh was able to track contextual information on its own as much as possible for generating the temporal and social information relationships. Two participants however felt that not everyone might want to migrate to a new system, taking into consideration the necessary time to learn a new system that is so different and the existing long-time investment in developing and maintaining a folder system. These participants felt that they were “*used to making do with what I’ve already got*” and “*tied to my world of labelled folders*”, which made it “*hard to imagine how it [InfoMesh] might change the way you interact or what sort of uses you might get*”. However, they were of the opinion that new users would probably find the views useful.

In considering InfoMesh for PDAs, several participants were “*positively impressed*”, largely due to the contextual nature of the views. These simplified views corresponded with InfoMesh for desktops and laptops (“*Looks like it matches laptop reasonably well*” and “*They’re close enough ... easy leap from one to another... having the same way of accessing and interacting*”), and so provided a consistent interface for viewing and reviewing their work on the go or when meeting with others (“*more for quickly looking up some information*” and “*it’s probably the sharing and showing to other people aspect that the PDA would be most useful for*”). One example given focussed on opportunities to discuss or share documents during chance meetings, as InfoMesh on her PDA would make that possible. Other participants were not sure how useful viewing all their information on a PDA would be, as they did not have PDAs or use them extensively even when they did. The latter was true especially as PDAs only supported limited work (for example, they would not edit a presentation on a PDA) and were used rather irregularly for appointments and some notes.

ASSESSMENT TASKS: INFOMESH INTERACTION AND USE

Question: What are user views on InfoMesh interaction and use?

Participants were able to use and interact further with InfoMesh through several small assessment tasks. These tasks focussed more on features provided by the views and FlexTools for annotating the activity space, as well as InfoMesh's ability to provide different perspectives on user work through the concept of Flexible Views. The tasks helped to further assess participant perceptions on InfoMesh interaction and use by changing view perspectives, and viewing or retrieving information using the information associations in the activity space.

Participants were comfortable using FlexTools and view popup menus to add and review item annotations, add markers to the activity space, arrange and colour code information items, as well as flag items as important so that they are added to the view's holding area. In fact, participants created information associations and annotations readily throughout the study while exploring and interacting with the interface. The main issues mentioned regarding this interaction were similar to the user preferences and suggestions gleaned from the exploratory tasks (e.g. certain options are easier to have access to from the toolbar, and marker selection and placement can be updated to support drag and drop). Participants felt that combining flexible views with FlexTools options made things easier to create and use rich views. They also felt that the various annotations were useful for describing and querying work in the activity space. Several participants further expressed their support for the filter and query style employed by InfoMesh, which would filter out specific types of documents or fade out items on their views that did not relate to their queries.

Subsequently, participants created a social view for Aran's 'World Cinema' activity, explored before as a map view. They used the menu system to create the social view for the existing user group 'Cinema Club'. They then explored the 'World Cinema' activity by surveying the new social view, and switching between its map and activity views by using the FlexTools View Contexts panel. Creating and switching views was mostly straightforward. Participants grasped the process and immediately incorporated the significance and usage into their

understanding and information-interaction. As participants created the social view, they repositioned the contacts on the view and immediately made inferences about the social information-interaction for the ‘World Cinema’ activity: *“He got some of these references from other people”, “I conclude that most of these links to shops are links that Aran found himself... and these are the ones these other people provided... two of them [bookmarks] seem to be very important”* and *“It wasn’t just Aran’s work that went into it... he obviously collaborated with other people as well... Coen has probably recommended these to him”*. One participant’s suggestion was to additionally list an activity’s remaining items (that were unrelated to contacts or location) to the side of the view simply for reference.

Participants switched between activity, social and map views for the ‘World Cinema’ activity through the FlexTools panel. This proved to be unnecessarily slow in practice for a central InfoMesh feature, as it required two steps (selecting the appropriate panel and selecting the view to switch to). In accordance, one participant suggested to move the option to the toolbar for easier access. In switching to the activity view for ‘World Cinema’, participants were once again able to make inferences about the activity, as to when Aran came across different online stores and when he read certain reviews.

Participants were positive about having several context-based perspectives of their information, as it highlighted specific aspects of the work and provided different perspectives on their information space. Participants also explained that the different contextual views provided several ways of remembering and finding information based on simple contextual details that are naturally remembered, without having to remember file names or go through large lists of items. Some of their comments were: *“It’s good to have different perspectives... and useful to see the flow of information... it’s nice to have a different, more visual view”, “It sounds very very useful”, “The more ways you can view it, the more views you’ve got, the better support you’ve got for remembering things or finding things”, “It [InfoMesh] gives you more opportunities to find things, it provides you with a wider picture of information”* and *“It’s a good way to get a different understanding of the same documents”*.

In discussing InfoMesh use, one participant revisited her real estate example to indicate how multiple, flexible views on the same information would help in

associatively retrieving information much more easily. If she had been looking at several houses, she may be able to re-find a specific house ‘A’ that is located near house ‘B’, but which she discovered at the same time as house ‘C’. She felt that multiple perspectives would allow users to solve problems and answer queries more naturally by working from the small contextual details we all remember. As InfoMesh tracks her research into real estate, she would not need to depend on her incomplete saved documents and web history listing to hunt down the house she wanted to retrieve information for. Another participant said however that the practical use of flexible views would be hard to judge for her personally, as she was used to managing with only one perspective using hierarchical listings of documents. She felt disinclined to adopt a new system of flexible views for accessing her information at this point.

COMPARATIVE TASK: INFOMESH AND HIERARCHICAL FOLDERS VIEWS

Question: How do InfoMesh flexible views on information compare to current hierarchical folder views?

In the final task, participants compared Aran’s InfoMesh views with hierarchical folder views of the same information (essentially for the ‘World Cinema’ and ‘Writer’s Corner’ activities). This task once again highlighted many of the strengths and weakness of both systems, as perceived and revealed in the first user study. In this study however, participants were exposed to more detailed InfoMesh views and the concept of flexible views, which included swapping between different views for the same information. Their exploration and interaction with the various views was also more in-depth, which consequently gave them more insight into Aran’s activities. The overarching perception in both the first and second studies is that InfoMesh and hierarchical listings offer “*different ways of organising*” information, each with its strengths and weaknesses.

Participants overwhelmingly stated that InfoMesh views allowed users to glean information relationships according to location, time and people that could not be deduced from traditional hierarchical file managers (e.g. “*The social one I like, it’s something you couldn’t deduce from a normal standard file manager, and same with the map one... all the three views you have are quite useful, even*”).

though at first I thought here this one [folder view] offers the time as well, but yeah only to a certain extent, yours offers a different information about the time...” and *“I cannot see anything at all [in the folder view] of did I share it with anyone, which part of the world do these belong to... I can see the temporal thing, when was it last modified... a rough sequence of events”*). Their comments reflected back on the context provided by InfoMesh views, but also significantly on the graphical representation of that context. For example, adding some collaboration information (such as author or collaborator fields) to an information list still does not provide the full and immediate impact of a graphical representation of social information relationships for an activity or task. Participants appreciated that the graphical views provide additional information relationships within the context (such as by information grouping and colour coding) and personalised annotations that would be difficult to replicate in textual listings: *“The folder view didn’t give me the colouring, and this [InfoMesh views] gives additional information about maybe connection to people or location, I can annotate it, I can see the time”, “you know where you got it from and who it relates to... you know where it comes from spatially”, “The folder view has absolutely no indication of where the documents are coming from”, “I cannot see any added comments. There’s no way to group things a bit or colour code them”* and *“It’s always been an annoying thing in folder structures, that you can’t easily annotate documents... directly associating them with files”*.

A couple of participants emphasised that InfoMesh additionally allows searches on these contexts, relationships and annotations (*“You don’t get annotations and the ability to search on those annotations [with the folder system]”*). Participants also favoured the thumbnail views in InfoMesh (*“Having a thumbnail view is very useful, which you don’t get with bookmarks in a traditional folder”*).

Folder views however provide fields of information that can be sorted (*“One thing I’ve always liked about folders is that I’m able to sort by one [field] and then you can just scan down the list and have a look, whereas it is perhaps not so easy to do with the time view”*). Hence, participants indicated that retrieving information that users expressly remember (by folder and name, timestamp, size or type) would be easy. They felt that the listings were however static and making sense of some of the context of their information would be harder. Two sample

comments illustrate this: *“The problem with the view here [folder view] is that you’re reliant on remembering names and things like URLs, unless you’ve given them sensible names it’s quite difficult... you have to go through it [the listing] and remember what they all are... whereas with a map view, you’ve got the geographical information to support those things... it makes it much easier to find what you want... It provides you with a wider picture of information, rather than just a static list of information which isn’t very helpful”* and *“I would probably have those [‘World Cinema’ activity bookmarks] in their own folders... drop them into regional areas... and drop the relevant bookmarks into them.... the problem I have always found is that is you can’t view them on one page... whereas on InfoMesh with the world map, you can see the regions and you see all the documents at once, which is a huge advantage”*.

At this point, their perspectives of InfoMesh use deepened. One participant said that her use of the views would cover *“a lot”* and *“anything”*. She expressed that *“the concept is really good”* and found all three InfoMesh views on information useful for dealing with both professional and personal work like documenting progress, mapping conferences, dealing with social networks and friends, and exchanging information with others. The comparative task increased participant interest in InfoMesh, especially in light of the surrounding detail the system provides for making sense of work. Several participants were expressly interested in InfoMesh integrating its current views with hierarchical folder views, to harness the strengths and benefits of both as part of one system.

Finally, two participants mentioned issues with privacy and security as InfoMesh made all of their personal information available from a single device, and with more detail and inherent meaning than hierarchical listings. As the system would carry all their annotated trails, information loss or theft would have more serious consequences. They suggested providing the option of switching off work tracking when required and the option of deleting items considered too personal. One participant also felt that when dealing with InfoMesh, certain views could be visually too demanding if there is a lot of data presented in them (e.g. a map view of a store with item placements and records).

END OF STUDY QUESTIONNAIRE

Question: What are user views on Pervasive Personal Information Spaces (as represented by InfoMesh) and their use, especially in providing access to their electronic information and supporting high-level activities?

Once again the final questionnaire used a variety of statements and sentence completions (very similar to the ones used in the first study) to gather user views on Pervasive Personal Information Spaces and InfoMesh. Participants first remarked on the following ideas:

- Having a single integrated information space that is accessible from all your devices at anytime.
- Having the system automatically register your use of documents and integrate your documents from different devices.
- Having overviews of the information space and the activities carried out.
- Having flexible visualisations that are based on contexts (like activity, time, place, device and people).
- Having tools to change the views on the information space according to time, activity, maps and people.
- Annotating your workspaces with colour, document grouping, notes, keywords and markers.

All in all, participant views on the concepts underlying Pervasive Personal Information Spaces were positive, as too on its support for ubiquitous information-interaction.

Participants deemed an integrated information space both important and useful. Several participants were eager to adopt and use a system like InfoMesh, as it would support diverse work anytime-anywhere. They felt that automatic tracking of work and device integration was both really useful in reducing user effort and ultimately a necessary part of such a system. Some issues mentioned related back to network problems or unavailability, which could hamper the system's use, as well as issues of privacy and security explored before.

Participants declared that overviews of their information space and activities were convenient to see which activities one has engaged in or is working on currently, presented together in one place (*"Nice and tidy to see what you've been working on... all in one place"*). Most participants felt overviews provided a good starting

point for resuming work as well as a faster means of navigating through time to see progress and revisiting activities based on time (*“Easy to find what you were last working on again”*). Activity interaction presented through histograms aided this access. A couple of participants felt that the views might not be that useful on a daily basis, but would be more useful for project work in tracking notes and progress.

Flexible views were further considered helpful to see information in different ways, as all information relationships are not always obvious in one context. Participants indicated that there is simply a preference at times to see information in one way or another. They asserted that flexible views were *“very useful in trying to find things again”* and making sense of information, especially with the ability to switch between views. They perceived that supporting tools provided users with much more control in manipulating views to answer queries or view the information in another suitable way. Specifically, one participant highlighted how some work might benefit from direct queries and other from information browsing in order to find information, and a system like InfoMesh supported both with a special emphasis on context-based browsing (*“Here you can search for something, then you have the broader context and browse the context related to it. For certain topics that will be excellent. It’ll always be good, but for certain ones it’ll be even more helpful.”*).

Finally, participants by and large considered it *“really useful to annotate things”* in a system like InfoMesh, as it allowed users to associate their ideas and findings from any document with that document. One participant said that paired with searches on these annotations, user effort is categorically reduced in creating separate ‘notes’ documents or scanning through numerous documents to track down important content. Another participant felt that annotations (item annotations, workspace markers and colour coding) were the most important aspect of the system for her, as it matched closely to the way she worked and processed information.

Asked once more about their views on InfoMesh use and work suitability, participants felt that the system was *“not limited to any one application”*. They indicated instead that it would be practically useful for tracking a variety of project, study and collaborative activities. Some example work mentioned

included doctoral research, conference organisation, knowledge management, travel planning and special interests (such as politics, science and movies). They underlined the aspects of annotating work, tracking progress, visualisation of work interaction, and information integration when working on multiple devices. One participant indicated that “*aspects of the system [were] very useful on their own as well*”. Another indicated her preference for InfoMesh because of its emphasis on the “*more visual and less technical*” presentation of information. Several participants said that “*switching from the familiar is hard work*”, but added that new large projects would benefit from the system and so provide some motivation to make the switch. In the discussion, participant preferences could be inferred to lie either with InfoMesh and Pervasive Personal Information Spaces or with the existing hierarchical folder views. All participants were however particularly mindful of the benefits and weaknesses of both systems.

Participants subsequently completed the same sentences as in the first study on the best and the most annoying things about InfoMesh and why InfoMesh would or would not work.

Participants highlighted a variety of aspects of the InfoMesh system as its best feature. These included the overview of work alongside the three different contextual views and perspectives on information, the integrated and synchronised access to the information space, the ability to use various annotations, and the colourful visual and spatial representation of information rather than a textual one. One participant echoed some of these statements and emphasised “*the ability to see an organisation of documents in a manner that our normal folder system doesn't provide, but is far more useful*”.

Similarly, participants brought forward different things that would make InfoMesh annoying to use. One participant said that views can look cluttered at times, and there may be too much visual information to make sense of. Another felt that too much of the metadata was still manual (e.g. people and location information relationships), which would require effort to maintain. Other responses related to InfoMesh still being a prototype and therefore not available for regular use, the system's slow performance on the study device, and the time required in learning the system and navigating the views.

In the second study as well, participants responded that the ideas in InfoMesh would work because they related to the way people think and work. They explained that the ideas applied universally, “*because everything you do has a context... has a time relationship... grouping based on some context...*” and InfoMesh in effect creates a “*knowledge management system that integrates the available information*” for each user. One participant also explained that the existing way of managing and interacting with information was overwhelming, as resuming work was a hassle due to the limited support for reminding the user of the previous state of their work.

Finally, participant reasons for why InfoMesh could be problematic revolved around cluttered views for larger activities (e.g. map views or views of web browsing activities), insufficient tracking of contextual and collaborative data at this stage (including contacts and emails), personal preferences of some users (e.g. preference for non-GUI interfaces for accessing information), user disinclination to switch to a different system, and technical issues with InfoMesh and network communications.

Expectedly, a general view held by the participants is that deeper exploration and real world use would help them assess InfoMesh better, with respect to its best and worst features, work support and appropriateness. This held true especially as InfoMesh targets life-long ubiquitous information-interaction and provides diverse views and features towards that purpose.

7.2.4 IMPLICATIONS

The second user study shifted its focus from InfoMesh visualisations to cover InfoMesh interaction and use as well, especially through the use FlexTools options. Many of the findings from this study directly support the conclusions from the first. At the same time, they clarified issues and suggestions for improving the day-to-day interaction with InfoMesh. (Appendix section C.1, Table C-2 summarises the study’s key findings as a reference.)

User perspectives still emphasised contextual visualisations as matching how they perceived and related information. They showed a preference for graphical views of information that allowed them to assimilate and retrieve details from their work, especially due to the personalised, flexible and contextual nature of these

graphical views. (Graphical here refers to the visual representation of contexts as a passage of time, a visual map, or a social network with photos and lines, all annotated with thumbnails, colour, grouping and view markers.)

User annotation preferences (for markers, colour coding, priority flags and notes) matched their own natural behaviour and intelligences. Some participants were more oriented towards colour, whereas others preferred using notes and priority flags to indicate similar information. These individual preferences uniquely shape the information space to match the user's activity and information behaviour. Users are not compelled to use the annotation or FlexTools options in a specific way. Still as they are available, participants can gear their use of InfoMesh features towards creating a related web of information that suits them, while largely forgetting about other interaction options.

Similarly view interpretation preferences would lead to some individuals using activity views more, and others social or map views, matching their symbol, person and object related intelligences. Their individuality would also dictate the different contextual cues they use to retrieve and recapture information through annotations, time, people, places, colour, markers, information associations and placement, and so on.

These findings are easy to understand when considering responses to the background questionnaire and how the context of the work completed the picture of participant activities. Time, places, people, goals, deadlines, devices, various notes, information sources and so on all made up the big picture of an activity. These details were left to incomplete notes or memory, which reduced the rich context of activity work to isolated pieces of information. Information access and retrieval suffered to some extent as a consequence.

An interesting finding was how readily InfoMesh views invited and encouraged user exploration and understanding of the activity space. The visual and contextual elements afforded a rich and meaningful activity space. This especially held true as work naturally displayed those temporal, social and spatial contextual affinities and gave rise to diverse information associations. Participants also felt that the visual and contextual cues supported overviews of work, perceiving the state and evolution of the information space, meaningful browsing and navigation, work continuity and a way to answer open-ended queries. Personal preferences

still dictated which views and view elements participants would favour in their own work.

Although largely positive, user remarks highlighted various usability issues and potential issues in the practical everyday use of InfoMesh on desktops, laptops or PDAs. Their examples of InfoMesh use covered a wide range of activities, frequently unique according to each participant's individual work, experience, information needs and information associations. InfoMesh on PDAs provided high-level information on the go and support for opportunistic information sharing and queries. Some participants favoured the views offered by InfoMesh to the folder system, others were unsure about the effort required to migrate to a new system, especially when they had already developed a detailed folder system for the work so far. User thoughts on their own use of InfoMesh can only crystallise through further exploration and real world use (e.g. the intricacies and practical use of associative or contextual retrieval of information, and the use of view switching, filters and queries).

The second study also investigated user views on FlexTools and InfoMesh interaction. Participants readily created annotations (through item priority, view markers, colour coding and grouping) and considered them useful to comment on and query elements of their work. They felt that FlexTools provided a way to enrich views and the information space itself. Consequently, flexible views allowed them to make inferences about the work from the available contexts and contextual details, by exposing a myriad of information associations and the evolution of their interests and work over time. With flexible views, a social view or activity view on a chiefly location-oriented activity, suddenly provides a different perspective on the activity, the people involved and work evolution. Participants' remarks were positive about this, as flexible views (especially through view switching) made it easy to use any of a number of naturally remembered contextual information to retrieve information. Changing the view perspective through the underlying context also supported information discovery and sense making from different angles.

The strength in the rich visual representations and information trails also lies with the personal aspect of the information relationships and annotations, whereby contextual retrieval and interpretation become transparent. The study underlined the value of rich and meaningful visualisations in information sharing and

archiving. Sharing these views would support another level of sense-making and social navigation. Similarly sense-making and recall would be much easier with striking activity spaces when retrieving archived work.

In comparing InfoMesh and hierarchical folder views, the second study underscored the findings from the first study. Information associations and contexts, as well as the impact of their graphical presentation lay at the heart of InfoMesh strengths. In comparing the two systems, participants appreciated how much more information they were able to implicitly glean from the annotated, visual presentations of activities and work context. Querying was further more versatile through view switching and manipulation, numerous contextual details and query tools. On the other hand, hierarchical listings of information provided a clean and sortable organisation, that made it easy to scan through document listings and easy to access remembered files quickly. The systems complemented each other, with the one richer and more visual, the other clean and technical. Participants did however feel the lack of a system like InfoMesh in the current scenario, which took their work content, context and meaning into account.

Support for the underlying ideas in Pervasive Personal Information Space, as explored through InfoMesh, was quite positive. Ubiquitous access of information through personalised, flexible views exposed the information relationships in user work and their meaning. Participants felt that this supported information-interaction more naturally and corresponded better to how people thought and worked. They felt that InfoMesh afforded a more appropriate, meaningful way of viewing things over time, in connection with people and places, as well as aiding memory, sharing information and carrying out knowledge work.

All of the InfoMesh features showed potential: information integration across devices, work overviews, flexible and contextual visualisations, personalisation through annotations and so on. Its challenges lay with getting full functionality in information tracking and integration, performance, view clarity and content. The challenge was also to make the leap to a new system such as InfoMesh easier on users, and manage privacy and security.

In getting InfoMesh ready for a longitudinal study, it was necessary to tackle some of these issues and the usability issues exposed in the study. With InfoMesh, a simple user guide is not adequate to introduce the system's views, tools and their use. Interactive video tutorials that tackle different features, example interaction

and use would be more beneficial in easing users into InfoMesh use. The features and uses would be explained from the point of view of a persona and his/her activity snaps, through a combination of audio descriptions, view element identification and video segments of interaction.

Of the various usability issues, several elements were updated first. Among other things, the naming schemes for views, recent activity pockets and timeline navigator errors were tackled. The filter and query tools and some other FlexTools elements were updated. Other changes such as moving specific view options to the toolbar, indicating current scroll or pan position on views, and updating the dialog for opening activities and views are left for a longer time-frame for updates. These changes would be beneficial for a full long-term study.

7.3 INVESTIGATING INFOMESH LONG-TERM USE

The short-term studies helped test the research hypothesis to a fair extent. Studying the long-term use of InfoMesh in the real ubiquitous computing environment can still more decisively evaluate the appropriateness and usefulness of InfoMesh and the Spaces model.

There are however several issues that put a full long-term study outside of the scope and time frame of this research. The number and complexity of the features and uses of InfoMesh that would need to be explored in the study were at the heart of these issues:

1. InfoMesh works on multiple devices, and to test ubiquitous access to information that is essentially supported by the interplay of information between devices, InfoMesh would need to be deployed and tested on at least two devices belonging to each participant. Moreover, these devices need to be networked and used periodically, which is hard to ensure. Temporary information exchanges through usb-drives would be feasible, but require significant additional effort from participants.
2. 'Long-term' in the case of InfoMesh would necessitate a study that was longer than two weeks, preferably a month, but ideally longer. The short time frames may not adequately indicate participant experience of InfoMesh. Specifically, they would not show sufficient activity interpretation over time, the creation and interplay of multiple activities, the generation of diverse information

relationships, the incorporation of various work context data to support contextual views, view personalisation, or view manipulation to answer information queries that occur over time.

3. InfoMesh is a prototype system. InfoMesh use would occur alongside all of a participant's electronic information-interaction, and so the prototype system would be used continually by participants during the study. Issues and complexity in its underlying functionality (especially with respect to inter-device communication, monitoring information usage, and information synchronisation) would make it difficult though to deploy it for a long-term study as a system that is sufficiently robust to recover from various errors in, for example, network communication or information synchronisation.
4. Evaluating InfoMesh use in the real world entails the use of various remote evaluation methods, including ways to capture, store and transmit study data. These methods would need to gather data on the use of InfoMesh (e.g. feature use frequency, interaction history), collect the artifacts of InfoMesh use (e.g. interval snapshots of views), and most importantly, capture participant experience regularly. An additional component would need to be built into InfoMesh to capture and store some of the collected data. Interval questionnaires could be administered through InfoMesh or a web-site, transmitting information back across the Internet. Phone interviews would then support discussions on participant views and experience. These would be conducted at specific junctures during the study and at the end of the study. The methods for data collection however need to be developed and reviewed for their appropriateness and practicality.
5. Finally, remote evaluation would also necessitate appropriate and stand-alone instructional tools such as interactive workbooks, tutorials and video demonstrations that allow participants to grasp and adopt an unfamiliar and multi-faceted system for the otherwise familiar and habitual task of information-interaction.

The decision was therefore made to approach a long-term study instead through a preliminary investigation conducted by the author. The investigation would explore real world use of InfoMesh in support of an activity commenced recently. Simultaneously, it would help understand and maybe resolve the previous issues,

as well as test the evaluation tools in preparation for a future study. Appendix section C.2 presents the study plan for the proper longitudinal study with details on data collection and evaluation measures. Appendix section C.3 reports in detail on the preliminary investigation.

The investigation limited the features and functionality explored in InfoMesh, by focussing on the InfoMesh desktop version employed on a single computer. The focus of the investigation thus largely rested on the interaction experience offered by context-based flexible views. By extrapolation, the investigation would capture some of the perspectives on ubiquitous access to information through these views. InfoMesh was tested over a period of a week to both predict the study duration that may be initially required to evaluate long-term use and to determine InfoMesh prototype robustness for supporting a long-term study. A remote evaluation plan drawn up for InfoMesh included requirements for both data collection and the InfoMesh component that would capture, store and transmit this data.

The decision to study InfoMesh through a single device was largely based on several observations. InfoMesh inter-device document transfers are affected by timeliness, session-based synchronisation requires consistent use of InfoMesh to ensure completeness in the information repository, and multi-device deployment and usage may only prove insightful over longer periods of study. Critically, multi-device use of InfoMesh would also require network availability and dependability. In a long-term field study, participants would need a home network for personal devices or perhaps an active network that connects their home and work computers to enable information exchange for ubiquitous access to information. This network connectivity however cannot be easily provided or ensured for participants.

The preliminary investigation largely offered a personal reflection on InfoMesh use in support of real-world activities. The author conducted the investigation by using the InfoMesh prototype on a single personal desktop in support of a leisure writing activity over a week's time.

With regard to the study plan itself, the preliminary investigation confirmed the anticipated feasibility issues, and supported the restrictions on study duration and devices used. The pilot study highlighted the study aspects that needed to be

changed, such as questionnaire lengths and sampling interval lengths. The pilot study also revealed that only certain aspects of InfoMesh can be realistically evaluated in a short time period, as some features (such as overviews for example) would only get used regularly over longer periods of time.

In its assessment of InfoMesh and Pervasive Personal Information Spaces, the investigation highlighted interesting and positive characteristics of the system, specifically emphasising its support for contextual and personalised access and retrieval of information. Time and location contexts, personalised annotations and activity spaces, and query tools that used all the underlying information, proved useful for visualising, resumming, interpreting and re-finding items. The interaction experience felt personalised and appealing largely due to the emphasis on unique, visual, personal webs of associated information over simply 'documents'. Once again, InfoMesh and the current hierarchical folder system showed their complementary natures, as both were easily used side-by-side during the investigation. A full-fledged field study and real-world use over longer periods of time will further help uncover other strengths and weaknesses, bring up uses that have not yet been discovered and perhaps limit some usage scenarios that were anticipated.

The preliminary investigation did however reveal several issues and the changes necessary for the practical use and deployment of InfoMesh in a field study. InfoMesh robustness (e.g. runtime memory errors and web activity tracking issues) and usability (e.g. lack of multiple item selection and difficulty panning large activity spaces) were at the heart of those issues and changes. The investigation also revealed the nuances and additions to InfoMesh features that may improve the ease of use and interaction experience beyond the usability issues uncovered in the pilot study and the former studies. Some examples include diagramming tools for marking view spaces, thumbnails that show large image versions of the underlying document on mouse-over, and a web-based component for InfoMesh views. There is also a benefit to building in a level of sophistication in the partially implemented and proposed agents, for registering contacts and locations for emails and documents, sorting incoming information into existing activities, and generating more of the required metadata automatically.

The pilot study definitely pointed out the limits of the prototype in testing out the underlying ideas, visual elements and functionality. Still, the current prototype

system served well to emphasise information integration, work context, view flexibility and personalised information spaces to reveal their advantage in (ubiquitous) information-interaction.

Overall, InfoMesh offered an interaction experience that was definitely more personalised. The views served as external memory, weaving and preserving a rich and meaningful activity space, which provided context to the work when interacting with and making sense of information, and which made querying, resuming and revisiting work that much easier.

7.4 DISCUSSING INFOMESH USER EVALUATION

This section summarises the key findings from all the phases of InfoMesh user evaluation, before discussing how they corroborate the hypothesis. The discussion subsequently reflects on findings from related developments, and their bearing on InfoMesh and Pervasive Personal Information Spaces.

7.4.1 KEY FINDINGS AND THEIR SUPPORT FOR THE RESEARCH HYPOTHESIS

In this research, the early focus group interviews, the two user studies and the preliminary investigation into long-term use, together provided insight into user information-interaction in the ubiquitous computing environment, user views on Pervasive Personal Information Spaces and InfoMesh, and various issues requiring attention. All these findings spurred on and directed further InfoMesh development, shedding light on the strengths and weaknesses of the underlying model. The key findings from the user evaluation are as follows:

- User information interaction encompasses multiple personal devices and activities, giving rise to various issues and work-arounds for managing information synchronisation and annotations. Much of the contextual details of user work are still only captured in user memory. Support for work continuity across devices, time and places is lacking.
- Participants grasped and were positive about the concepts underlying Pervasive Personal Information Spaces captured in the Spaces model, namely information integration across devices, automated information tracking, information views according to contexts (time, people and places),

personalisation of the activity space through annotations, and view flexibility through view switching and querying.

- InfoMesh was deemed useful for a variety of activities and ubiquitous access to information as well, supporting work continuity, opportunistic information behaviour and information sharing. Users felt that InfoMesh views on the information space were personalised and expressive, as they supported various annotations and offered multiple perspectives. Accordingly, they positively remarked on InfoMesh support for interpreting work and making inferences, having an overview of work and tracking its progress, accessing and retrieving information contextually, resuming work and switching between activities.
- InfoMesh interaction was largely natural. InfoMesh views also proved to be inviting, encouraging browsing, implicit searching, sense making, learning and social navigation. Users voiced that contexts (like time, people and places) and the resulting rich informative spaces are natural to the way users think, work and perceive information. As anticipated, each individual's information behaviour and natural intelligences dictated their preferences for InfoMesh views, interaction and annotations. Consequently, information interaction and the resulting views would closely match the user, as well as their work.
- InfoMesh strengths lie with embracing contexts, annotations and view flexibility to produce rich, associative information spaces. The system complemented the folder system, but lacked its direct simplicity and technical detail. However, participant remarks underscored the current need for a visual and meaningful information space and personalised interaction, as explored through the system and Pervasive Personal Information Spaces.
- Users identified a range of usability issues with InfoMesh, and indicated that potential future pitfalls for InfoMesh lay with technical problems in keeping information synchronised across devices, limitations in automatically tracking contextual details, privacy and security, and user reluctance to learn and migrate to a new system. (Appendix section C.4 lists recommendations for future InfoMesh development and evaluation based on the uncovered usability issues, user suggestions and early design ideas.)
- The preliminary investigation into long-term use was promising and underscored many of the user findings from the previous studies. The interaction experience was both more personalised and meaningful than that

afforded by the current hierarchical folder views. However, the investigation revealed the work required on InfoMesh robustness and usability before a full field study can be carried out.

The research into Pervasive Personal Information Spaces hypothesised that *context-based flexible views provide better contextual, ubiquitous access and visualisation of information than current single-device metaphors*. The findings from the user evaluation of InfoMesh largely confirm that supposition.

Pervasive Personal Information Spaces chooses to support ubiquitous access to electronic information by integrating and relating information across devices. Users largely felt that this would reduce their need to consciously synchronise information (e.g. as with copying across specific documents or emailing them), as well as properly meet unexpected queries and opportunistic information needs (e.g. answering queries or sharing information through whichever personal device was on hand). As such, information access and availability through InfoMesh on their desktops, laptops and PDAs was poised to offer easier *ubiquitous access* to their information than the current folder system.

Participants felt that context-based flexible views provided a more appropriate and meaningful way of viewing information over time, in connection with people and places. They remarked that the contextual details and associations allowed them to better assimilate and retrieve information, as well as review and carry out their work. Consequently these views seemed to provide better *contextual access and visualisation of information*, than hierarchical document listings.

The context of user work is personal, made up of the who what where when why and how that characterises and informs user activities. Hierarchical folder listings of information miss many of these details. InfoMesh user evaluation showed that participants appreciated views embracing these personalised contextual details when presenting their information. They felt that context-based flexible views revealed more of the implicit and explicit contextual details of activities, thereby providing a *context for their ongoing work*.

The user studies however showed that Pervasive Personal Information Spaces do more than what the hypothesis postulates and something of what it only implies. Information interaction is not just contextual but also personalised. Flexible views do not just support information access and visualisation, but also show promise in

supporting information space navigation, associative and contextual information retrieval, work continuity, creating striking activity spaces, interpretation and sense making, information foraging and discovery, archiving and sharing information trails, and social navigation.

Still, Pervasive Personal Information Spaces have their limits. The user evaluation showed that InfoMesh weaknesses are the strengths of the hierarchical folder system and vice versa. Consequently, systems like InfoMesh are not replacements for folder views, but complement them. Hierarchical folder organisations provide tidy sortable listings with technical details, focussing on user documents and categorisations. Pervasive Personal Information Spaces offer a more personalised and meaningful information-interaction, anytime-anywhere, emphasising user activity and work context.

7.4.2 FINDINGS FROM RELATED DEVELOPMENTS

There are few directly related developments to Pervasive Personal Information Spaces, and fewer whose user studies can provide some feedback for the user evaluation on InfoMesh.

Pervasive Personal Information Spaces built on several ideas from previous research into TimeSpace (Krishnan, 2003 and Krishnan and Jones, 2005), which concentrated on temporal workspace visualisations for representing user activities. TimeSpace evaluation and user studies conducted on systems related to TimeSpace (such as LifeLines (Plaisant *et al.*, 1996), ThemeRiver (Havre *et al.*, 2000), Interlocus (Nomura *et al.*, 1998), and TimeScape (Rekimoto, 1999)) highlighted many elements that showed potential for supporting user work, information sense making and retrieval. TimeSpace and LifeLines largely supported the idea of a temporal overview, for providing users with a bigger picture of the underlying information space. In TimeSpace and in InfoMesh, such an overview can capture the state, progress and evolution of the information space and provide a context for current work. Visual cues like colour in LifeLines and ThemeRiver, and PostIt notes in TimeScape helped users make inferences from views on the information space. Combined spatial and temporal views as in TimeSpace and Interlocus helped understand work progress. TimeSpace especially showed the potential for offering users a different perspective on their

information space that portrayed the evolution of their information space and helped interpret that changing space.

TimeSpace sheds light on using timelines with workspaces as presented in InfoMesh's activity view. The ContactMap system (Nardi *et al.*, 2002) illustrates the value of visualising social networks. An early study showed that it required a lot of effort to remember the people in their social networks, their connections to each other, their details, details of which documents were shared with whom and so on. User evaluation of ContactMap showed that users naturally organised their social networks according to groups (e.g. work groups, projects, friends, family, special interests), which is in alignment with InfoMesh social views that depict social networks according to specific project groups or simply according to spontaneous social networks that form as part of an activity. Unlike ContactMap, in InfoMesh people can belong to many groups, which proved important to users in the study of ContactMap.

The Chandler system (OSAF, 2008) is in regular use, where users are positive about its ability to bring all their tasks, emails and appointments together in one place as collections of information supported with detailed views. A study on applications built for Gnowsis (Sauer mann and Heim, 2008) showed that they were most used for project and event management, and note keeping. Essentially, Chandler and applications built on Gnowsis provide more personal information management support. As their interface does not specifically visualise the presented information and information relationships, studies on their use do not add much to the user evaluation on InfoMesh

The study on Feldspar (Chau *et al.*, 2008) focussed on the usability of its user interface for performing queries compared to Google Desktop and Microsoft Outlook. The study showed that query success and completion times were better in Feldspar, and user views were positive about its use and ease of use. As the study focussed on interface usability, the queries and study procedures were not geared towards how users may use the interface in reality. However, information retrieval in Feldspar allowed users to make use of information connections easily through the interface.

Feldspar and InfoMesh both try to capture those associations. InfoMesh emphasises their visualisation, especially as this can provide more implicit information about the user's work context and evolution. Feldspar's emphasis is

on information retrieval alone. Still, they complement each other in the area of actively specifying and implicitly visualising information associations. InfoMesh's contextual view and query options capture something of Feldspar's objectives, as manipulating contexts and then applying queries to the resulting view works to incrementally specify relevant associations. For example, the user can select an activity (e.g. "World Cinema"), then choose its social view (as seen in Figure 4-22), and then issue a query (e.g. for the term 'Magazine'), which results in the relevant search results highlighted in the view. Effectively this query specifies the following incremental associations: an activity, the people involved in that activity, the documents shared with or by those people, and the specific word associated with one of the document titles. This query then answers the question '*What was the online magazine that someone shared with me related to foreign films?*' from Aran's perspective. As the results are displayed within the context of the view, the query can essentially be used to target a different search, namely for the name of the person who shared that document with Aran (i.e. '*Who shared that link to an online magazine related to foreign films?*'). This type of associative retrieval, that also makes use of the contextual visualisations, found support in the study on InfoMesh (e.g. through a real estate example given by a participant in the second study) and was perceived as especially useful since InfoMesh could provide anytime-anywhere retrieval of this information to satisfy opportunistic information needs or queries.

Overall, the studies conducted on various related developments support and highlight only specific aspects captured in InfoMesh. The many different facets of InfoMesh together approach user information interaction in a new way. InfoMesh user evaluation so far has been positive, but a longitudinal field study can shed more light on how the ideas might ease and personalise information interaction, and how successful and useful these ideas may be in everyday computing.

7.5 SUMMARY

The user studies and investigation into InfoMesh use helped approach and test the research hypothesis over several stages of the system's development. This chapter reported on the second phase of InfoMesh user evaluation, which focussed on eliciting user views on context-based flexible views, and the interaction and use as

offered by an interactive desktop and PDA prototype system, before considering the system's long-term use.

The second user study broadened earlier user evaluation to include InfoMesh interaction and use and supported many of the findings from the previous study. Users remarked that contextual visualisations matched how they thought, worked and perceived information. The strength of InfoMesh essentially lay with its capture and depiction of information associations and contexts, accessible ubiquitously through personal devices. These associations and contexts had a powerful impact through their graphical representation, which stood out for all participants. This flexible visual representation invited and encouraged user exploration and understanding of the activity space, and supported a wide variety of information behaviour such as resuming work, annotating and personalising the information space, interpreting information and making inferences, and supporting associative and contextual retrieval of information.

The preliminary investigation into InfoMesh long-term use reviewed the learning materials and remote evaluation methods needed to carry out a longitudinal field study. Simultaneously, the basic investigation supported previous findings and uncovered new details on InfoMesh use through its use in support of a leisure activity for a week. InfoMesh features that stood out were still its associative and contextual retrieval of information, and the personalised views of the information space and information interaction. The views essentially formed a picture of user activity, where the visual and contextual cues act as a powerful trigger to recall and make sense of information, and notice associations and work patterns.

All the user studies revealed the complementary nature of the current hierarchical folder system and InfoMesh, chiefly because of the former's simple organisation and the latter's rich, personalised visualisations. The studies also uncovered a number of usability issues and potential issues in the day-to-day interaction with InfoMesh, which are tackled by various recommendations for further development and evaluation of the system in the Appendix.

User views and reactions all supported the overall vision for InfoMesh, in providing rich, associative information spaces for personalised, ubiquitous access of information. Consequently, the study findings offered strong support for the hypothesis that context-based flexible views can provide better contextual,

ubiquitous access and visualisation of information compared to current day single-device systems like the hierarchical folder system.

The next chapter now explains how the strengths of the Spaces model can be leveraged for other user domains, by presenting guidelines for developing Pervasive Information Spaces. The thesis then concludes by considering the contributions made by the research and ideas for future research work.

CHAPTER 8: CONCLUSION

This thesis has presented the research into Pervasive Personal Information Spaces, considering the background research that informed the work and modelling the underlying ideas to create the Spaces model. The Spaces model proposed tracking user information usage, integrating their distributed information space, and visually presenting their work as rich, contextual and associative activity spaces, in order to provide better contextual, ubiquitous access and visualisation of user information.

The thesis subsequently followed the design, development and evaluation of the InfoMesh system, an example implementation of Pervasive Personal Information Spaces. InfoMesh user evaluation showed that the underlying Spaces model could support information interaction in the ubiquitous computing environment in a way that corresponded with how users thought, worked and perceived information. Existing electronic information-interaction was regarded as lacking this harmony, which made sense making less implicit and re-finding information less natural.

Pervasive Personal Information Spaces applies the Spaces model to the domain of personal information collections. However, many domains can benefit from the integrated, context-based flexible views characterised in the framework. This final chapter now describes how Pervasive Information Spaces can be developed for different domains by employing the Spaces model, and provides step-by-step guidelines based on the work carried out for Pervasive Personal Information Spaces and the InfoMesh system in this research. The chapter then presents the conclusions of the research into Pervasive Personal Information Spaces, summarises the research contributions and details ideas for future research

8.1 GUIDELINES FOR DEVELOPING PERVASIVE INFORMATION SPACES

The Spaces model can help with developing Pervasive Information Spaces to support user information-interaction in a variety of user domains. These can be personal, public or organisational domains, dealing with digital libraries, organisational information systems, online databases and so on. Flexible views, visual contexts, and rich, associative information spaces can potentially support learning, knowledge building, interpretation, information foraging and discovery, information orienteering and associative retrieval, information sharing and social navigation, as well as meaningful archiving for many user domains.

Pervasive Information Spaces can selectively realise different aspects of the Spaces model, according to the problem space investigated. Some can emphasise information trails for sharing and browsing, others flexible views for supporting learning and knowledge building, and yet others for integrating ubiquitous information-interaction to support activity continuity. Some examples for applications of Pervasive Information Spaces (described in more detail in Appendix section D.2) include:

- Associating user information interaction across online medical and health resources.
- Managing research review work through the visualisation and access of research article collections¹.
- Tracking knowledge and group projects in a company's research and development department.
- Developing a Pervasive Information Spaces for medical practitioners that combines their research, research reviews, conferences and practical experience across information databases and resources.
- Creating a Pervasive Information Space for the home that encompasses the growing number and variety of devices and their leisure use in the domestic space.

Each type of Pervasive Information Space may emphasise different goals, but still make use of information trails, contextual views and overviews, which are appropriate for most domains to personalise visualisation, interaction and retrieval. Information integration is an implicit necessity in all these cases, to support seamless ubiquitous access to information and work continuity. Personalised, rich information spaces become more useful when anytime-anywhere-any context style of computing is supported. Information-interaction then provides a personalised computing experience wherever the user happens to be, mitigating device isolation problems and information management tasks.

¹ A fellow research student, Daniel McEnnis, mentioned this problem space in February 2008 to invite visualisation ideas. The author subsequently analysed the problem space and drew up several views adapted from the flexible views paradigm to meet the information interaction goals.

The research into Pervasive Personal Information Spaces and the development process to implement the underlying ideas in the InfoMesh system can be used to provide guidelines for developing Pervasive Information Spaces for other domains. These guidelines consist of 6 steps as summarised in Table 8-1. (These steps are woven together with the PSA-based design and development process.)

Guidelines for developing Pervasive Information Spaces	
Step	Detail
1) Analyse user domain	Analyse the user domain, emphasising user information interaction. Develop personas, activity scenarios and an information space snapshot.
2) Explore contexts	Explore the contexts of importance to information-interaction from the user's and their activities' perspective. Depict context snapshots for some of the activity scenarios.
3) Apply Spaces model	Consider and adapt the Spaces model for the user domain. Rewrite activity scenarios tailored to an implementation solution.
4) Adapt flexible, contextual views	Select and adapt contextual view designs, their content and supporting tools. Build activity snaps for selecting, adapting and assessing the views.
5) Develop the system	Adapt the Composer-Worker-Presenter architecture to implement information integration, automation and communication, and flexible views. Write out task scenarios for testing the implementation.
6) Evaluate the resulting Pervasive Information Space	Evaluate the prototype system in several stages to investigate the views, view content, use and appropriateness for the domain.

Table 8-1: Guidelines for developing Pervasive Information Spaces

Analysing the user domain essentially focuses on understanding and detailing the who, what, which, where, when, why and how of relevance to the domain (as done in section 3.2.1 for personal information spaces). Who considers the target users of the domain, what considers the user work or activities, which the information accessed and used, where and when look at the work environment,

why reflects on user goals, and how considers the devices of importance for work in the domain. Exploring these questions helps examine the problem space and the particulars of user information-interaction in that space. Specifically, considering the user and their information-interaction can shed light on the appropriate personalisation and uses of flexible views for the problem space. Once again, to emphasise and support user work, it is important to consider high-level user activities, rather than generic tasks.

Analysing the user domain and carrying out focus group interviews and field studies, can then help develop personas and corresponding activity scenarios and information space snapshots (as illustrated in sections 3.2.2 and 4.3.1 for the persona 'Lisa'). These design artifacts are especially useful in developing Pervasive Information Spaces as they can capture user activity to envision and guide the design of personalised view content.

In the research and development organisational example, user activities might highlight the use of collaborative information trails for idea development and insights. These trails could support information navigation through landscape markers that indicate new ideas or changes in the research direction. Organisational information spaces may also show a need for information trails and views that support research familiarisation and training for new team members. The social context of team members and responsibilities, and physical contexts of company branches or labs and associated work may also apply.

Exploring the contexts of relevance to user work aids in understanding the contextual details that inform that work, specifically from the user's perspective and from the perspective of their activities and activity information. These contextual details would map onto views, view elements and options for supporting context-based, flexible views. Exploring the contexts involves detailing the who, what, which, where, when, why and how that apply to the user's information work, i.e. the social, activity, information, physical, temporal, goal and device contexts as described in section 3.2.1. A good way to visualise and itemise these various contextual details is through context snapshots for some of the activity scenarios (as done in section 3.2.2 for the persona 'Lisa' and her 'Newsletter Column' activity).

In the example of tracking health and medical information access, the information context might reveal the need to track user health goals (such as weight or cholesterol levels), new habits and ongoing results as specific information items or annotations, alongside the relevant articles of interest and research carried out. Contextual associations might include relating various health stats to the body (e.g. as a map), supporting comparisons with goals or ideal stats. The social context might involve people with similar goals or issues, who share researched information and recovery progress and so on. Sites participating in creating this type of Pervasive Information Space can provide trail and view templates for users to use and share, which can be personalised through their interaction and preferences, and archived for reference. Similarly, in supporting annotations for enriching the information context, they can offer domain specific view marker tools and FlexTools panels (e.g. for charting or tracking health goals, stats and guidelines).

Applying the Spaces model requires considering the elements of the framework and adapting them for the selected domain. These elements, described in section 3.3, focus attention on creating an integrated information space, managing the automated processes and information communication, as well as delineating appropriate context-based flexible views for building a Pervasive Information Space. Each user domain needs answers to for example where an information repository is maintained, which elements of user information interaction and context need to be tracked additionally, and which flexible views and tools would best support user information goals in the domain. Once these details are known, activity scenarios can be rewritten to match a potential system implementation. These scenarios can then help visualise information interaction further and help develop activity snaps in the next step.

In the various examples given before for instance, a question might arise about how to make these spaces pervasive. In adapting the Spaces model, decisions need to be made about where and how to maintain a full information repository, and how access to this information is supported. In the research and development department example, the information repository could reside on servers in the organisation, providing secure remote access to devices when users travel or work from home. User health and medical information trails and views can support a

local information repository like InfoMesh and an information repository online for view sharing through verified accounts.

Adapting flexible, contextual views comes next. Section 4.2 explored and visualised the design space for implementing flexible views according to the Spaces model. The core flexible views fall under work views for directly supporting activity work and information trails, context-based views for highlighting specific perspectives on activity information, and overviews of the information space. These views achieved their flexibility through the versatile FlexTools. This research highlighted the benefits and interconnectedness of all these graphical views through InfoMesh user evaluation; most Pervasive Information Spaces would benefit from these core views. Activity views and their chronological information trails can support work continuity, work interpretation and information sharing. Context-based views such as social and location-based views would allow users to track, browse and discover information relationships. Overviews can support browsing, navigation, sense making and more. The selected user domain, however, may emphasise some views over others. View elements and tool options would also need to be selected, adapted or extended to match requirements for the problem space. Building several activity snaps (as illustrated in section 4.3.2) can support the process of determining the appropriate views and view elements, as well as extending and assessing the final choices.

In the previous example domain of research paper collections, some of the key goals include searching and browsing with context kept intact, as well as information orienteering, foraging and exploration in the document space. Flexible overviews of the information space can support these goals and direct users to information detail. Information trails would largely act as a reference for what has been read and how the research interest has evolved.

In studying this domain space, the universe view (explored in section 4.2.2) was adapted to support searching, browsing and information discovery, with complementary hierarchical tabulated views of the same underlying information (see Figure 8-1 to 8-3). The underlying partial activity snap considered the research space investigated in this thesis and its broader subject areas. Interaction and navigation elements of interest included adapting navigation and view detail

to the zoom level and area of interest. The FlexTools filter and query options and criteria were tailored to the document space and relevant metadata.

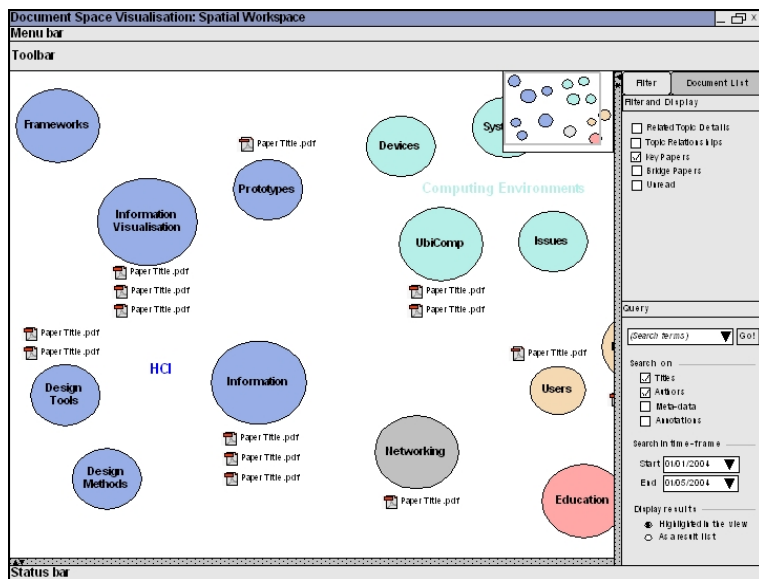


Figure 8-1: Flexible spatial visualisation giving an overview of the document space and key topic papers, with no topic selection

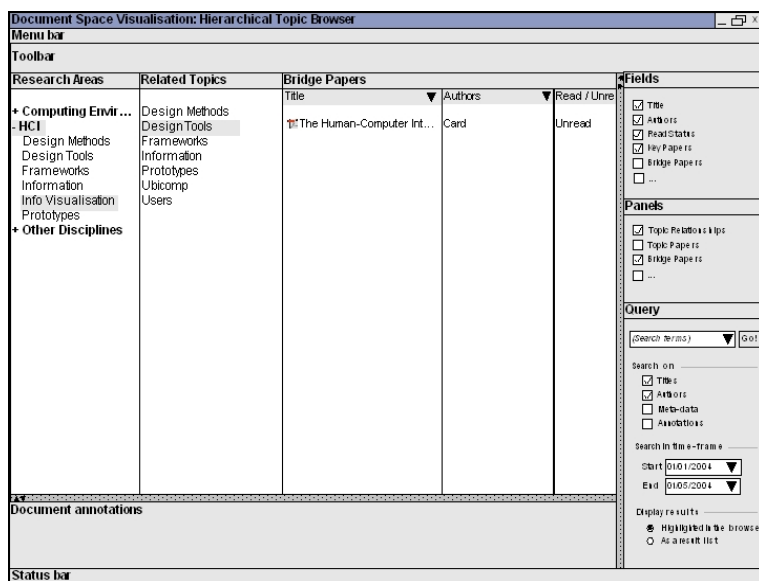


Figure 8-2: Hierarchical tabulated browser visualisation displaying topic relationships and bridge papers

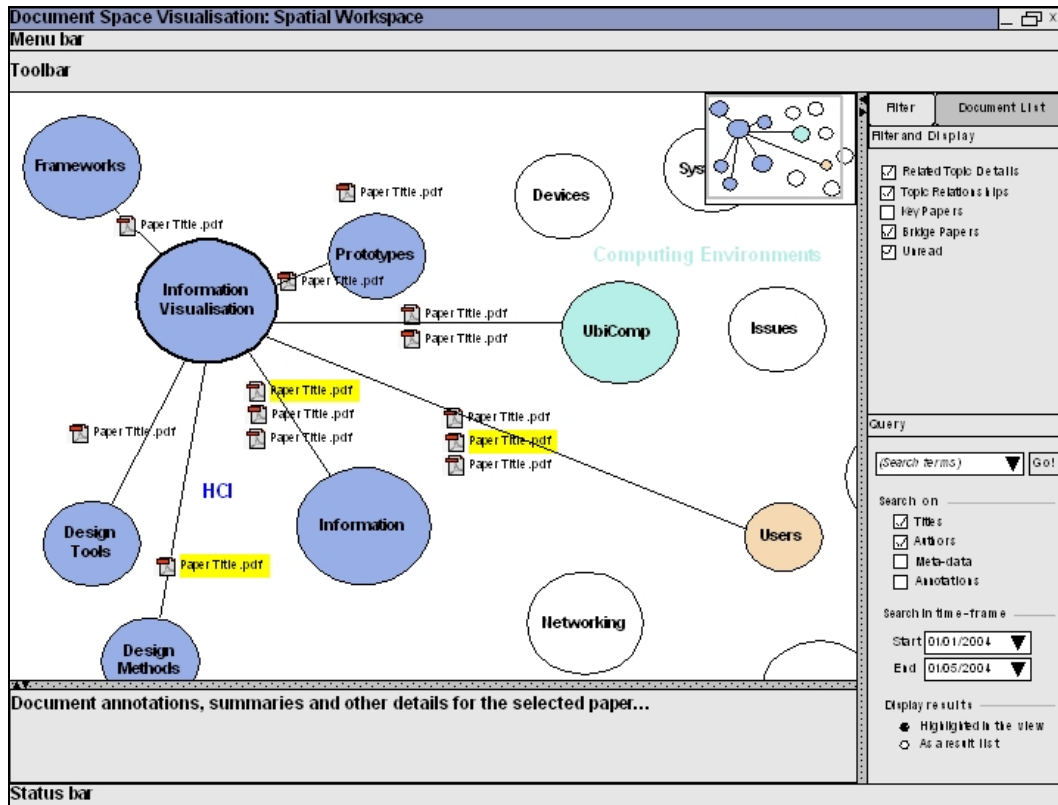


Figure 8-3: Flexible spatial visualisation selectively displaying topic relationships and bridge papers according to a selected topic

Developing the system then involves adapting the Composer-Worker-Presenter architecture (presented in section 5.3.1) to implement information integration, information use and context tracking, information synchronisation and flexible views. Considerations would include the right environment for creating flexible and cross-platform applications that can be adapted to different devices, as well as privacy and security requirements, information tracking and synchronisation protocols, and the structure and site of the information repository. Task scenarios for previously developed activity snaps (like the examples provided in section 5.2) can help test system functionality at this stage.

Similar to the widespread nature of hierarchical folder organisations and the versatile use of web browsers, an adaptable skeletal system supporting Pervasive Information Spaces can be quite useful for any of the example domains or others. That is, the system can implement the fundamental environment of the Spaces model on any device or platform to then support additions and extensions for creating and managing different Pervasive Information Spaces. This system can download specific component extensions (such as tailored composer, presenter

and worker elements) for a specific Pervasive Information Space, where the corresponding information repository can be on a network server (e.g. organisational information spaces) or a web server (e.g. public or web based information spaces) or secured as a local element. Presenter and worker element additions or extensions (such as specific communication protocols, FlexTools options, domain information tracking) would be downloaded as features, agents or services on the local device. The system can then integrate user information interaction across various domains into the user's Pervasive Personal Information Space if needed and if there are no privacy or security restrictions (such as with some work related material).

Evaluating the resulting Pervasive Information Space helps with understanding, refining and finally employing it. InfoMesh evaluation in chapters 6 and 7 showed that flexible views benefit from several stages of evaluation. Early on the studies help select views and view elements for the domain and refine them according to user perspectives. Later on user evaluation sheds more light on use, usefulness and user interaction experience. User-subjective evaluation with activity snaps can provide more insight into user preferences and interaction behaviour, which is of special importance as key goals stress personalising the interaction experience and improving information sense making. A longitudinal field study can more accurately assess real world ubiquitous use and usefulness.

In the example domain of research paper collections, user subjective evaluation can utilise activity snaps generated with details of their last research activity and topics in mind to evaluate their perspectives on view support for information browsing and discovery. In the example of health and medical information resources, user subjective evaluation can be adapted to provide generic activity snaps and information trails (e.g. diet resources and information trail for gluten intolerant individuals) specifically relevant to the participant. Though this does not capture their individual activity, it captures their individual interest, and can therefore show how useful these views or information trails may be in the domain for information sharing, learning and social navigation.

8.2 CONCLUSIONS

The conclusions of the research into Pervasive Personal Information Spaces reflect directly back to the research question ‘*How can we integrate, personalise and contextualise information to provide effective support for ubiquitous access to personal information spaces?*’ and the sub-questions asked in section 1.2. The sub-questions delved deeper into how the research question may be answered.

The research question was answered by developing the idea of Pervasive Personal Information Spaces (section 3.2), which was modelled in the Spaces model (section 3.3), and implemented and evaluated as the InfoMesh system (chapters 5 to 7). Pervasive Personal Information Spaces focused on the particulars of personal information spaces, high-level user activities and the contexts of relevance to user information work to effectively support ubiquitous access to personal information spaces. The Spaces model crystallised these ideas and tackled the research question and sub-questions as follows:

- *How can high-level user information activities be supported in a ubiquitous computing environment?*

By supporting user work by tracking and presenting personal electronic information according to high-level user activities.

- *How can the presentation of and interaction with the user’s information space be modelled to match the user’s entire use context?*

By supporting contextual information interaction by incorporating the user’s activity, information, social, physical, temporal, goal and device contexts in the user’s views on their information space to better reflect their work context.

By also generating flexible views for ubiquitous, contextual access and visualisation of information on personal devices. (Flexible views are tailored to user activity, preferences, work context and device capabilities to support work in the ubiquitous computing environment.)

- *How can personal information spaces across multiple devices be integrated to support contextual access and visualisation of information?*

By integrating distributed information in an information repository richly defined through information relationships and associative details to support context-based flexible views.

- *How can the user's work or activity context be presented and preserved across devices and locations?*

By automating information monitoring and synchronisation across user devices to help preserve user work and activity contexts, and reduce information management overhead.

In doing so, the Spaces model described a way to support a more personalised computing experience, allowing people to focus more on their activity information-interaction and less on managing their documents. The hypothesis was then postulated that *'context-based flexible views provide better contextual, ubiquitous access and visualisation of information than current single-device metaphors'*.

User evaluation of the InfoMesh system helped confirm the research hypothesis to a degree, with participant remarks and perspectives indicating that context-based flexible views may indeed provide better contextual, ubiquitous access and visualisation of information than current single-device metaphors such as hierarchical folder views (section 7.4.1). The main reason was the rich, visual, associative information spaces created by context-based flexible views that more naturally matched the way people thought, worked and perceived information. As a consequence, work resumption, information interpretation and contextual information retrieval were all considered easier.

Rather than focus on measures such as task or information retrieval times, the user evaluation in this research took a more qualitative and user-subjective approach in testing the hypothesis, especially as Pervasive Personal Information Spaces emphasised a personalised interaction experience and personalised activity support. Hence the emphasis was on carrying out in-depth studies with fewer participants during several iterations of system development. The consequent findings may be less generalisable, but offered more meaningful insight into user views and the underlying concepts, as well as useful insights into refining the ideas and the system. Long-term use of systems like InfoMesh can help support or reject the hypothesis more definitely.

The research into Pervasive Personal Information Spaces has its limitations and is far from complete. Like Haystack, MyLifeBits and other systems reviewed in

section 2.7, Pervasive Personal Information Spaces aimed to create an integrated digital information environment to overcome information fragmentation, but also to improve and personalise ubiquitous information interaction. The difference was the emphasis on user activities, contexts of use, and flexible views of the information space that were graphical and associative.

This research has unearthed both the strengths and weaknesses of the concept. Personalised, graphical views of the information space afford quick interpretation of information and user activity. Over time, however, the graphical representations can become overwhelming for some activities as they become more populated (and cluttered) and harder to navigate. User contexts provide a natural web of information that supports contextual and associative retrieval of information, but they can be hard to automatically register and register correctly or appropriately. When users have to specify them manually or arrange or rearrange large graphical views, this can create extra overhead, the very thing systems like this aim to reduce. Similarly, it is hard to decide how much contextual information and information-interaction needs to be tracked, and what is pertinent or valuable. In tracking web use with activity work for example, meaningful information can become embedded in ever-increasing trails of information that may or may not all be useful, a consideration for all systems that aim to create *digital lifetime stores* (see also Tan *et al.*, 2007). Finally, anytime-anywhere access to a rich web of personal information supports activity continuity and opportunistic information behaviour. Technological and other limitations can however hinder fast, easy and accurate integration of information across devices to provide anytime-anywhere access.

Nonetheless, all approaches considered in related systems reviewed in chapter 2 and Pervasive Personal Information Spaces as investigated in this thesis offer insight into improving information management and information interaction beyond the limitations of the current computing environment. Haystack unifies all data across application formats using metadata. The Universal Labeler uses a single labelling scheme to unify and organise information for projects. Pervasive Personal Information Spaces, exemplified through InfoMesh, offers flexible, personalised views of the user's distributed information space according to user activities and contexts.

8.3 SUMMARY OF CONTRIBUTIONS

The thesis work makes a number of research contributions, indicated previously in section 1.4, that are summarised again here. Primary contributions:

- *The concept of Pervasive Personal Information Spaces* marries integrated digital information environments with personalised, contextual information interaction for the ubiquitous computing environment. The social, activity, information, physical, temporal, goal and device contexts are conceptualised and analysed for their relevance to user information work and consequently Pervasive Personal Information Spaces. Pervasive Personal Information Spaces seeks to preserve and appropriately display user context to support anytime-anywhere information access. (Section 3.2)
- *The Spaces model* is a conceptual framework for developing Pervasive Information Spaces that emphasises information integration, automated information collection and synchronisation, and flexible views. The model combines a variety of original and familiar, inter-related aspects in a novel way to support personalised, ubiquitous access to information. (Section 3.3)
- *The flexible views paradigm* results in rich, visual, associative information spaces for supporting associative and contextual information visualisation and retrieval. Flexible views allow users to change the view on the underlying information space to match their work context to facilitate resuming work, interpreting and querying information. Flexible views incorporate user activities and other contextual details in representing and providing access to distributed information. The views achieve flexibility through versatile FlexTools that for instance support annotations, view markers, view swapping and context manipulation, and contextual filtering/querying. The flexible views' design space incorporates work views, overviews, a number of context-based views, and an array of FlexTools options. These views show potential for supporting a variety of information interaction including information orienteering and sense making, lifelong learning, life logging, information space navigation, social navigation, and pictorial archiving of information. (Sections 3.3 and 4.2)
- *The InfoMesh prototype system* for desktops, laptops and PDAs, serves as an example implementation of Pervasive Information Spaces for the selected user

domain of distributed personal information spaces. The system also serves as a test-bed for evaluating Pervasive Personal Information Spaces design concepts. Evaluation of InfoMesh helped support the hypothesis that *context-based flexible views provide better contextual, ubiquitous access and visualisation of information than current single-device metaphors*. (Sections 5.2 and 7.4.1)

- *Guidelines for developing Pervasive Information Spaces* build on the lessons learned in developing and evaluating InfoMesh. The guidelines consider the user domain, contexts in information work, development tools (personas, scenarios and activity snaps), the Spaces model, flexible views, the Composer-Worker-Presenter architecture, and user evaluation specifics. (Section 8.1)
- *The activity snaps design and development tool* can be used alongside personas and scenarios of use to aid all the phases of system development. Activity snaps can capture realistic, annotated user activity trails and can help design, refine and evaluate interactive systems, which specifically emphasise visualisations and real-world user activities. The PSA life cycle describes their creation and use in the system development phases. InfoMesh development serves as a case study for the use of activity snaps in the system development cycle. (Section 4.2, 4.3, 5.2 and 6.2)

Secondary contributions:

- The thesis provides *a review and synthesis of related research*, emphasising frameworks and theories, users and information, the ubiquitous-pervasive computing scene, models and techniques of interest, relevant issues, as well as related systems and some of their limitations. (Chapter 2)
- Studies conducted for the research uncovered *specifics of everyday information-interaction and user needs for ubiquitous computing* useful to understanding and developing solutions for ubiquitous information interaction. These include details on:
 1. Everyday user information interaction with multiple personal devices, covering information activities, storage and synchronisation, as well as individual differences and preferences, which affect that interaction.
 2. User appreciation of multiple, flexible views on their information space that incorporate contextual details and personalised annotations. These

views were thought promising for providing improved support for anytime-anywhere information access, activity continuity, sense making, information orienteering, contextual and associative information retrieval, sharing information and potentially archiving information. These views were also complementary to views provided by hierarchical file managers.

3. User need for a visual and meaningful representation of their information space and a personalised interaction experience. (Chapters 6 and 7)
- *The Composer-Worker-Presenter architecture* for Pervasive Information Spaces can flexibly support different implementations of the Spaces model and provides the design for an interwoven information model for relating user information items, contexts, annotations and other associations. (Section 5.3.1)

8.4 FUTURE RESEARCH

The concept of Pervasive Personal Information Spaces lends itself to further research in several directions. Some of the underlying ideas can be explored in more detail (such as contexts in information work, classification of information space annotations, and user intelligences and graphical views), whereas other ideas have revealed a number of research opportunities for the near future. The research goals however still centre around improving and personalising the user computing experience and user information interaction, so that individuals can focus more on their activities and interests, and less on managing and making sense of their documents. Some of the ideas for future research are given below.

Pervasive Personal Information Spaces: Delving deeper into device and information space integration that takes into account mobile phones, digital consumer electronics and storage devices, alongside desktops, laptops and PDAs. The research into Pervasive Personal Information Spaces is young, leaving much room for exploration and development, especially with respect to the flexible views paradigm and support for full interactive interfaces for PDAs and other handheld devices. Longitudinal studies that take into account everyday computing with multiple user devices would also be important here.

Wearable devices to support Pervasive Personal Information Spaces: An investigation into how small wearable devices (such as the ‘Beamer’ device explored in Appendix section D.1) can augment Pervasive Personal Information Spaces, especially with respect to maintaining privacy and security, as well as applying context-awareness to sporadic information interaction. (A simple example would be the incorporation of Seagate’s D.A.V.E platform released recently). The wearable device would expand the realm of the user’s personal devices to include public devices at libraries, Internet cafés and airports for example. This topic belongs in a broader area of research that includes work on the Oxygen project (MIT Laboratory of Computer Science, 2002) and the Aura project (Carnegie Mellon University, 2003). The interest in this research area is evident from the large-scale projects carried out in different institutions, as the research is promising and applicable to the commercial development and real-world use of a new breed of devices and computing environments.

Information retrieval in Pervasive Personal Information Spaces: This topic looks at two separate ways of information retrieval and access. A) A further exploration of the visual querying and filtering interface for InfoMesh that supports contextual presentation of search results. B) An investigation into speech-based information retrieval to support hands-off, remote information access and retrieval for Pervasive Personal Information Spaces. This last idea focuses on simple day-to-day media information retrieval by users in a pervasive computing environment, in support of immediate non-computer-supported activity.

User information trails and social navigation: An exploration into the different kinds of information and activity trails created when users interact with personal information spaces, digital libraries and the Internet. This topic also covers a study of user work and information contexts, personalisation of information and services, and how these inform and affect information interaction and visualisation. Some of the planned future research considers how these information trails can support social navigation online.

Adapting view flexibility to user intelligences: A study into individual user preferences in information interaction with respect to information visualisation,

contexts, visualisation styles, annotations and so on. Understanding these preferences can give insight into diverse user intelligences and learning styles and how they influence electronic information interaction. This insight can help tailor activity spaces to each user's natural interaction preferences. With flexible views, this understanding can lead to providing the same underlying information model across multiple devices, but adding another dimension of view flexibility on top that can be adapted to each user's personal traits to best support implicit information interaction and interpretation.

Archiving information pictorially according to user activities: The flexible views paradigm allows users to access their work as an activity trail with contextual details and personalised annotations. When information is archived with the annotated visual trail, it has the potential to make information sense making easier in both personal and public collections when users revisit information items. A study into the strengths and weaknesses of archiving information pictorially can help understand and improve how users back up and retrieve information, and grasp revisited information.

Subjective user evaluation for information-rich interactive systems: When evaluating interactive systems that store and present personalised information, objective user evaluation may not suffice. The usual method for collecting subjective information on user experience is the use of standardised opinion questionnaires (e.g. QUIS at www.cs.umd.edu/hcil/quis and SUMI at sumi.ucc.ie). The activity snaps design tool developed in the research work has the potential to take subjective user evaluation further, by not only incorporating user opinion, but by incorporating user activity information in the prototype systems evaluated. Carrying out several diverse prototype evaluations using activity snaps can help investigate how the tool may provide further insight into user experience when developing information-rich interactive systems.

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APPENDIX

A. FOCUS GROUP STUDY

A focus group study was drawn up to uncover participant views on and use of ubiquitous devices by using an interview format. The study was conducted over two small focus group sessions. This section reports on the study in brief.

A.1 PURPOSE AND PROBLEM STATEMENTS

The purpose of carrying out the focus group interviews was to first gain added insight into individuals' use and interaction with ubiquitous computing devices, information collected and organised on these devices, device integration within the daily interaction context, as well as their expectations for their device interaction. The interviews were secondly used to assess the potential for Pervasive Personal Information Space technology as well as participants' attitudes towards it. The interview findings helped with refining the underlying ideas and the requirements for Pervasive Personal Information Spaces.

The study was designed to provide insight into the following questions:

- What are individuals' views on ubiquitous computing devices and their use?
- How do they use, interact with and manage information on different ubiquitous computing devices, such as laptops, PDA's and mobile phones?
- How do user devices and device use fit into day-to-day activities and work environments?
- How do individuals store, organise and synchronise information across devices?
- What do they expect and wish of their multi-device interaction?
- What are their views on the concept of Pervasive Personal Information Spaces and the potential use of the technology?

A.2 METHOD

Four participants took part in the focus group interviews over two sessions. The sessions were held in the group user lab of the Usability Laboratory in the Department of Computer Science at the University of Waikato. An audio recording was made of the sessions.

Participants were selected with ample computing experience, long-term experience using a variety of portable and handheld devices, and with some individual differences (e.g. gender, age, information behaviour and device preferences). The participant group was kept small to provide initial insight into user views on ubiquitous device use and as a supplement to findings from user studies on various information behaviour.

Following many of the suggestions presented by Silverman (2000), the interview process was run in a couple of informal “mini” focus group sessions. Participants were provided with a script a couple of days before the session, which presented some background information, several questions to help reflect on their views and use of ubiquitous devices, and details about what they can expect and what is expected of them in the interview.

The interview sessions made use of a set of questions and “non-directive probes” to guide discussions and elicit participant attitudes, behaviour and practices regarding ubiquitous computing devices and the concept of Pervasive Personal Information Spaces. Other techniques used in the interview included guided visualisations, story telling, and sentence completion to get insight into how people approach tasks on their different devices, how their activities and device interaction progresses over longer periods of time, and what their views might be on Pervasive Personal Information Spaces (see Silverman, 2000, and Ede and Nielson, 1997).

The interview started with a discussion on everyday device use. Participants were then given an introduction to the research context and the idea of Pervasive Personal Information Spaces and asked for their views on the concept. Consequently, the interview mainly gathered qualitative information, such as:

- Details of the kinds of information stored on different devices, the organisation and overlap of these pieces of information, and the synchronisation styles used and issues with synchronisation.
- Descriptions of the use of these devices according to time, environment/location, main activity and device activity, next to views on devices and device integration.
- Listing of device, interaction and use preferences, as well as common problems and issues with devices.

- Details of what individuals would like to see supported, their levels of satisfaction with their current interaction with devices, and their views on the advantages and disadvantages of Pervasive Personal Information Spaces.

This information was subsequently used to understand user activity and preferences within the ubiquitous computing environment, user support for the ideas in Pervasive Personal Information Spaces, and user information-interaction details for formulating domain, persona and scenario descriptions.

A.3 STUDY FINDINGS SUMMARISED

The study findings offer much support for the ideas and motivation behind Pervasive Personal Information Spaces. Simultaneously, together with findings from other studies, they also help with detailing the user domain and developing the personas and scenarios used throughout the research.

A.3.1 DAILY INTERACTIONS WITH MULTIPLE DEVICES

1. Give me some examples of your main daily interactions with computers and handhelds. When do you use each? What do you use them for? How do they fit into your time and space, and how do they fit into what you're doing?
2. Paint me a picture in words of your interaction with a desktop / laptop / PDA / mobile over the last week. Give some examples/scenarios. Where are you when you use them? What's your preferred way of interacting with the device? What other activities are you engaging in when you work at them? How would you characterise your use of the devices?
3. Give me some examples of uses you really appreciate, and some of problems and issues you've encountered. How do you feel during the regular use of your devices? Tell me about what would happen if you didn't have your desktop / laptop / PDA / mobile to use for a week.

Even in the small focus group, the devices used and device interaction varied considerably. Participants used different combinations of devices, including multiple desktops at different locations, laptops that combined work and personal use and came along on travel, and smartphones and PDAs largely used to track contact information, appointments and notes. They worked with devices running

different operating systems, logged remotely into some computers, and applied diverse synchronisation protocols for transferring files between devices (e.g. email, online storage sites, storage devices such as pen drives, PDA synchronisation software, offline synchronisation managers). Their preferred interaction modes included predictive text, keyboard and (ergonomic) mouse, and even the ‘*annoying touch-pad*’ that users got comfortable with after a while.

Participants varied in their wish or ability to keep work and leisure based activities separate in their device use. Device issues often altered their device interaction. For example, many of them limited their use of PDAs and smartphones, as device synchronisation was difficult or at other times simply impossible. Similarly, devices running different operating systems or on different networks also led to further device isolation as transferring information became cumbersome. This finally led to “*document madness*” and “*information madness*” as participants found it “*very difficult to get [information] between one device and another*”.

Device use and interaction routines varied with each participant. Here, individual differences and preferences affected when certain devices were used (e.g. emphasis on device use mornings or nights), how work was done (e.g. working only on the laptop or carrying out specific work on a designated desktop to minimise file transfer problems). Participants always carried their PDAs, smartphones and cell phones with them as they performed a reminding function as well.

Participant activities ranged as expected across work (e.g. research, programming, presentations, writing), information tracking (e.g. contacts, appointments), and leisure activities (e.g. online shopping and financial transactions, music and videos, news, health management). Each participant’s information space captured a unique subset of all of these kinds of activities. Some participants shared certain devices with others (e.g. family members). They all shared a wide range of information (e.g. music, contacts, files on a personal file server, opinions) on a wide scale through email, web sites and online communities.

Participants’ individual viewpoints also differed about their interaction and relationship with their devices, reflecting their preferences and personalities (e.g. seeing computers as chiefly assistants to work versus seeing them as an integral element in their hobbies and leisure activities).

Device uses that were appreciated or considered an issue also varied. Some liked the synchronisation available for their phones and PDAs, while others hated it as it did not work for them. The participants that made use of an electronic calendar, especially appreciated its remind function. All participants however lamented the lack of communication between devices, and felt that automating many of the information management and synchronisation process would make things easier. Search features were deemed very important, as some documents were simply very hard to remember or find. Hence search options provided another potential handle on files (as opposed to file names and file locations alone). Other viewpoints that came up included the idea that devices were not really as portable as they seemed and created issues for easily carrying work, and that PDAs would prove more useful if they could move information items between devices or locations. Several participants also voiced their ideas and support for better opportunistic use of information. One participant provided the story of wanting to show someone a picture of a pet and realising that she had it with her on her laptop, which proved handy.

A.3.2 INFORMATION STORAGE AND SYNCHRONISATION OF MULTIPLE DEVICES

4. Give me a description of the information you store on desktops / laptops / PDA's / mobiles. Which pieces of information have the most importance to you on each device? Describe your reasons. List the kinds of information that are common to all your devices, or information you consciously synchronise.
5. Tell me what goes on when you synchronise devices. What's the motivation? What steps do you follow? Which pieces of information do you synchronise (on PDA's, mobiles, laptops and desktops) and how do you organise them?
6. Imagine that the information storage on these devices is your desk. What's the desk look like? What's your attitude towards this desk and the state of the desk? Imagine that your information storage on these devices is a tree... Describe your tree. What would you like your tree to be like instead?

Participants stored and organised information in unique styles. They frequently stored separate, overlapping sets of documents on their devices, and keenly felt the isolation between their various computing devices (e.g. *"It's hard to get access*

to both, both the stuff at home and up here, at the same time"). There were worries about hard-drive crashes and data loss, and a desire for better options for persistent data storage as well as automatic and continuous ways of backing up the information collection.

Participant information collections uniquely mirrored their work and interests, and were for example comprised of work and research related documents, photos, videos, music, web site pages and bookmarks, address books and calendars, alongside further information items specific to certain interests.

Information storage seemed to take on many forms, some of which served as a way to keep information backed up, or central and available from other devices. In the focus group interview these included:

- Information kept locally on a single device, or copies on several devices. Information could be partially kept on a single device according to the interaction through that device (e.g. PDAs carried calendar information), or one computer acted as a main information base and was used extensively, with information only transferred to other devices when necessary.
- Documents and pieces of information emailed and kept on the email server (e.g. *"I had to e-mail my work from the laptop to the desktop, even though they were both just there"*).
- Information stored locally on a site (e.g. useful information in an online support community, or online file storage).
- Documents stored on external storage devices such as pen drives and CDs.

Items in their information collection were backed up in different ways and consciously synchronised between devices either regularly or as needed. One participant backed up all her most important documents once a month on CD and to her main device. Others periodically backed up their important work documents, photos and calendar details. Two participants regularly backed up their main documents by attaching them to self-addressed email (*"Then there is the e-mail server, which has my life on it, and if that dies I'd be really really peeved"*). Backups were often kept in multiples (e.g. multiple CDs, devices or physical locations) to prevent loss. Some of these storage solutions were considered long-term backups (e.g. CDs), and others short term (e.g. email).

On other occasions, information was synchronised when it was needed for a task or change in situation (e.g. copying across flight details on a PDA and current

work onto the laptop when travelling). The motivation for synchronising information was the need to share information or to have certain files on another device than the one they were on. Synchronisation methods mainly involved a manual transfer of documents through file selection and copying across to other devices, using a network, email or intermediary storage devices such as USB pen drives. Some of these manual transfers got complicated as they required multiple steps and devices (e.g. transferring photos from a digital camera to the device with the appropriate software installed, before transferring the photos to another computer that is generally used to email the photos to others). Less frequently, participants made use of synchronisation managers, such as PDA-desktop sync software and Microsoft offline file managers for two intermittently networked computers. These last methods however had some issues (e.g. problems running the PDA sync software) and limits (e.g. limited to two specific computers), but were more streamlined and took less effort when functioning properly.

In general, participants explained that they used multiple complicated processes for just transferring and backing up information (*"I do a lot of backups... to keep them correct and up to date there's a need for just remembering exactly what you have done... it's [easy] to forget bits and pieces... What do I have where?"*). All these processes took effort, but also time (*"When I'm working on docs off-line, they take a while to load, and it's doing this every time, and it shouldn't have to"*). One participant started avoiding the issues associated with synchronising files, by predominantly reducing his interaction to only a single device (*"I always have the laptop with me... that's why I specifically don't have a desktop and use my laptop solely... to not have the hassles of transferring files constantly and looking for [the latest] versions [of documents]"*).

Participant organisation styles varied between very detailed and precise organisation schemes (e.g. deep hierarchical categories and elaborate naming schemes) and styles that were less planned out. In all cases, information stored was extensive, with multiple overlaps and ordered using various organisation techniques. Some of the information was stored in well-categorised folders, whereas others were thrown together as with *"piles of paper"*. Some participants created a simpler but less balanced folder categorisation that mostly revolved around a set of top-level folders (e.g. work, email, music). Where some participants preferred an approach that produced shallower hierarchies, others

preferred complex folder hierarchies with depth. They both had their negatives. Shallower hierarchies were often unbalanced and cluttered (*"I can describe [the organisation] as one big branch about to snap off... probably a few branches"*). On the other hand items in complex hierarchies were often too many levels down for easy access (*"I just find that for example the thesis chapter I'm working on currently is stored in a folder that is so far down the hierarchical list, it's just ridiculous. It's easily ten steps down. It shouldn't have to be that complicated. I shouldn't have to keep it in one gigantic folder... I wouldn't be able to find it. So any way of organising documents without ending up with just one huge folder or a huge depth [is good]."*).

The interview unearthed several idiosyncrasies. One participant used to store information in folder hierarchies in Microsoft Outlook specifically because of its filters and their use in tracking down pieces of information. Another participant duplicated folders and entire folder levels, as certain items belonged in more than one folder (e.g. a document that was kept both in the 'chapter folder' and the 'writing folder' with links to connect them, as the document contained part of a thesis write-up). She felt however that they did not always work correctly, with issues in keeping the files updated and making sense of their relationships. Naming files consistently and appropriately, and renaming certain items like photos was considered hard in all these organisation methods, especially since names were soon forgotten or hard to remember.

Unlike the real world, participants kept items in electronic information collections for much longer. Some participants had furthermore largely stopped deleting files, as they might need to review it many years down the road (*"I used to delete things I basically don't delete things anymore... It's happened a lot, that two years down the track you are wondering what you did then, because you need to go back and do something new"*).

Regardless of the organisation and naming styles used, participants complained that locating things could get difficult (*"Hassle just findings things and getting to them, partly because it becomes so complex"* and *"When you're working on it, it's alright, but when you go back to [the same folder organisation] after 6 months, it doesn't [make full sense] ... it gets quite tricky"*). They felt that there should be other ways connecting related items (*"You can have folders for some things, but*

there should be other ways, at least ways of linking things together in other ways, and seeing how they are linked together”).

A.3.3 USER EXPECTATIONS FROM THE USE OF MULTIPLE DEVICES

7. Imagine your devices can freely talk to each other. What kinds of information would you wish them to share automatically? What would you want them to do with this information?
8. Imagine your device was a genie in training. What would you ask of it? What are the kinds of things you would expect it to learn about your ways of interacting with your device? What are your expectations of what it should be able to do?
9. List one very useful feature, one very exciting feature, and one if-only-that-were-possible feature you would like your desktop/laptop/handheld/mobile to support and how it would change your day.

Participants expressed that the ideal when it came to information sharing across devices was ultimately to have access to their needed documents from different locations or devices automatically (e.g. *“I would like to share services between here and home such as documents and applications so I that I could work at home exactly as I would work here”, “I would love to have access to my work documents wherever I am... My bookmarks... frustrating when I’m elsewhere and needing it”* and *“having access to stuff from here on any computer though would be handy”*). There were some fears about how to trust systems in their security and ability to automatically transfer files. As these services were as yet unavailable, there were also some questions as to how users might make use of them once they were in place (*“Part of it is that we’re not used to be able to do it... if we were who knows what we’d do with it... what we could actually [do with] it”*). It was still unclear how devices outside of the personal device circle would fit into this scheme. Currently, USB pen drives and emails were considered the easiest options (when available) for transferring individual files from new devices or locations (e.g. devices in the library or at a friend’s place).

If devices were genies in training, participants stressed that they should only learn and adapt if they could do it properly. They liked to have their devices to give

personalised alerts for various events and perform a reminding function for recurring events and information back-ups. One participant's comment once again emphasised devices talking to each other and sharing information automatically (*"I would like things to talk to each other without me having to tell them. I would like it when my devices come... are close together, that they talk to each other, saying 'hey I've got something for you'... and just do it without bothering me."*). She also expressed a need for a *"proper, recently used items list"*, something that allowed her to return to her previous work easily.

Features that were considered most useful were calendars, email, device reliability. The most noted feature on participant wish lists was a multi-faceted reminder system, a *"psychic reminder system"*, for providing alerts and reminders of events, recurring tasks and work. Participants considered features related to automatic device communication and information transfer to be a very exciting feature (*"Definitely the automatic thing, where I don't need to worry about it... really like the idea of doing backups."*).

A.3.4 ATTITUDES TOWARDS THE CONCEPT OF PERVASIVE PERSONAL INFORMATION SPACES

1. Explain what your initial reactions are to this idea. What do you understand under this concept? What do you expect this technology to do if it is in place?
2. Give me some example scenarios of how your daily interaction with your computers and handhelds would be with this technology in place. How would your interaction and use of devices have changed? Tell me about your attitudes towards this change.
3. Complete the following sentences:
 The best thing about this idea is...
 The most annoying thing about this idea is...
 This idea would work, because...
 This idea would not work, because....
 What will get people to really use this concept, accept or like this concept is the realisation that...
4. If you were trying to get others not to buy into this idea, what kind of arguments would you use? If you were trying to get others to buy into this idea, what kind of arguments would you use?

Initial reactions to the idea expressed both excitement about the possibilities and uncertainty about issues like reliability, security and privacy. Example reactions included: *“It would be fantastic”, “If it worked and it was secure I would use it. Security and privacy though are huge issues”, “Good if it could access different kinds of media: web, e-mail, spreadsheets ... good if it could track down stuff I looked at before related to what I'm doing now”, “If I could say - find all the information relating to this translation - it would be really good cool”, and “also when you're changing places [moving from one place to another]... it would be nice... it I still had direct access to it”.*

Participants felt that the technology had both everyday and long-term uses, as in the current approach files *“get lost in the file system, lost among different applications”*. One participant put forward the following scenario: *“Long-term uses... in the folder system you have all the stuff you've worked on over years. Over years you seem to get rid of or don't want the stuff, but after a longer time, in the long term, suddenly you might want to access that stuff just for historical purposes even. The file system doesn't support that and kind of makes things unmanageable”*. The feeling was that users would want to see the documents they used and were working on at different times before. These should not crowd out current work and current views on the information collection, but instead be easy to bring up when needed.

The technology largely spoke to participants since it would relate information pieces together automatically and could potentially reduce time spent managing and synchronising information: *Great. I like the seamless, high-level representation, which is readily available wherever you go. I really like it that they automatically relate documents and pieces of information together. I don't even mind setting some things up manually, that's fine.”, It would really reduce time overhead and frustration overhead as well from swapping stuff between places etc.”* and *“having to manually sync you always have to think about where something is currently stored and where it needs to get stored”*.

Participants felt that the technology would change their interaction so that *“you wouldn't need to always think about where you're saving something”* and *“you'd use I think things a lot more in what I would think is natural... instead of thinking to put it [a document] here, then move it onto another machine consciously because you need to use it there later and get it back off of there later. It's*

ridiculous the way you have to think about things now". The emphasis was very much on the more 'natural' interaction the technology offered: *"It would be way more natural. There wouldn't be such a huge separation between locations and what data you have access to..."*, *"and operating systems and devices [expressed by another participant, that everyone agreed with]"*. Participants felt that this way they would be able to focus more on their actual work rather than management tasks (*"Absolutely, a lot of the stuff I do is just overhead time, it really is"*).

Participants were asked to complete a few sentences to elicit their views on what the best and annoying aspects of the idea would be, and why it would or would not work. The best thing about the idea was that it would save time, reduce overhead, specifically because the idea offers *"a more natural way of interaction"* and as it *"would be a solution to a problem that's widely recognised and... in most people's sub-conscious... or anyone dealing with multi-device or multi-platform [situations]"*. Participants felt that the most annoying thing about the idea would be if it did not work and that *"it is not going to happen soon enough"*. Some also worried about the inherent risks involved with respect to security and privacy. They stated that the idea would work was if it really saved time. However, they said that *"there needs to be a lot of technology that needs to be there behind the scenes"* such as faster network speeds and also an initial push for the technology to be adopted. Moreover, participants felt that what will get users to really accept this concept is the realisation that *"the way we are currently doing things sucks"* and *"that it actually works and would make a difference"*. All adopters of the technology would also ask themselves *"Is it secure? Can I use it? Is it going to make life easier? Is it going to cost a lot?"*. They expressed that *"people do want this stuff, they just don't know it yet"*.

Arguments for the technology once again focussed on time savings, especially time saved to spend on actual work: *"I think especially if people appreciate how much time it can save"*, *"I guess just thinking about things that matter rather than mucking around and thinking about storage"*, *"About expending all your energy where you should be... like if you're working project your main concentration energy should go on the core of your project not all the surrounding bits"*, and *"It always ends up as 70% of the time spent on file management and 30 on the actual project."* Similarly arguments against buying into the technology focussed on security, reliability, actual functionality and ability to save time, costs, data

integrity and loss of control (e.g. *“it’s not secure it’s not safe”*, *“doesn’t work, doesn’t save you time”*, *“loses documents”* and *“if it breaks you can’t fix it”*).

B. SYSTEM IMPLEMENTATION DETAILS

The specifications presented in this section elaborate on the application classes and procedures that perform the functions of the InfoMesh Composer, Worker and Presenter components, which were described in section 5.3.1.

B.1 APPLICATION CLASSES AND PACKAGE HIERARCHY

Underlying the InfoMesh application components are various information, communication, worker and interface objects and relationships. They provide the blueprint for the broad information structure and system pathways for InfoMesh, and are largely similar for the different devices.

B.1.1 INFORMATION OBJECTS

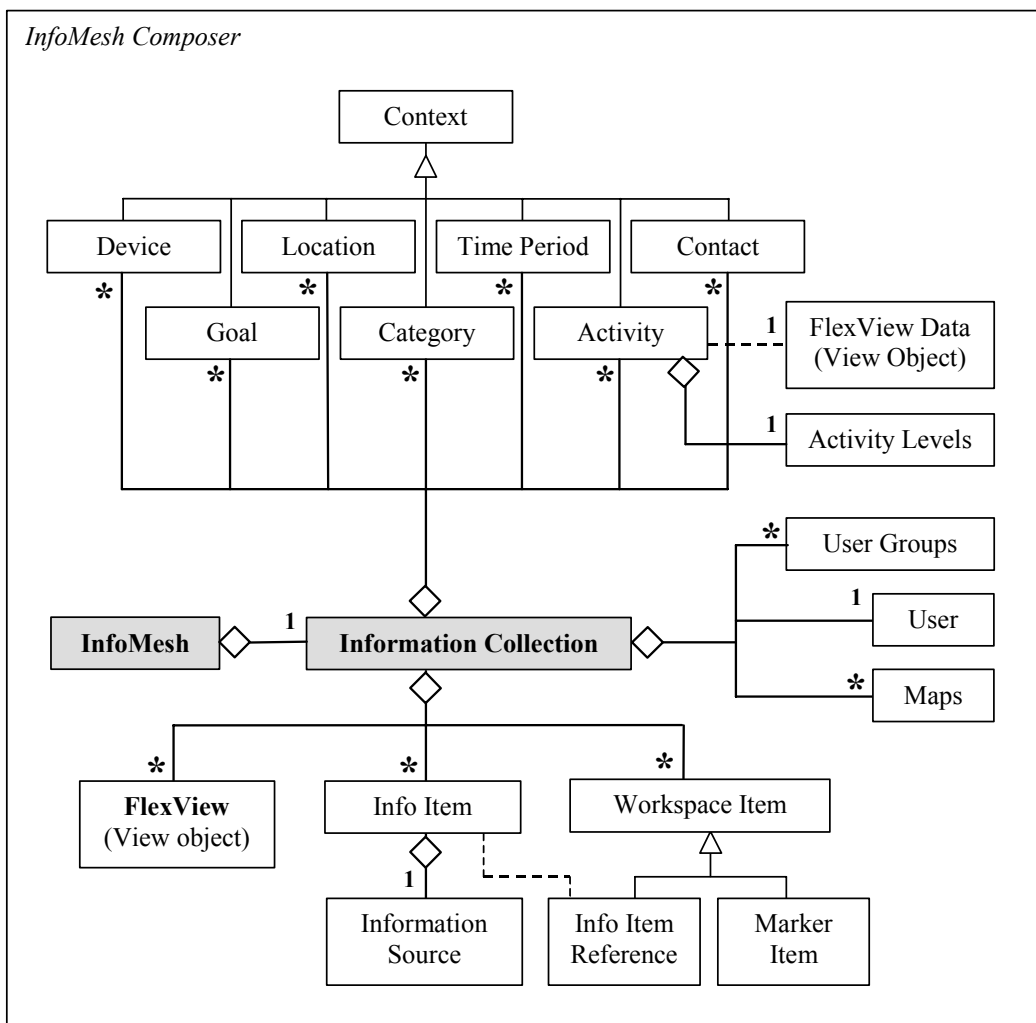


Figure B-1: Information object relationships

Conceptual information objects in InfoMesh include the information collection itself, the user, contexts (contacts, devices, categories, activities, locations, time periods and goals), information items, information sources, user groups, workspace items, and views (see Figure B-1).

- Information collection: The information collection object represents the user's entire electronic repository, and tracks details of all the user's contexts, information items and views. The information collection links back to its user, and tracks current views as well as aggregate information on the collection contents and status.
- User: The user object represents the owner of the personal information collection. Details stored and tracked by the object include user identity (e.g. name, login information), secondary identities (e.g. roles with respect to certain activities), user groups and preferences.
- Context: Sub-classes of this class represent the different work and information contexts related to the user, such as activities, contacts and devices.
 - Activity: The activity object represents a single user activity within the personal information space. Properties tracked for activities include title and status information, start and end dates, activity levels, flagged items, associated goals, associated view and consequently, references to associated information items. Activity Levels store details about usage periods and usage levels for each activity (taking into account, for example, frequency of activity use and number of documents accessed) so that users can assess the level and progress of activity.
 - Category: The category object acts as a grouping entity, for grouping related information items within an activity or perhaps across activities. Information items can potentially also be loosely clustered or added to a category by users, through workspace arrangement, keyword anchors and colour coding.
 - Contact: Each contact object tracks details for a single individual of relevance within the user's personal information space, through identity details (e.g. name and contact details), group membership and roles, and access privileges.
 - Device: Device objects represent each of the user's personal computing devices used to manage and interact with the information space. Properties

stored for each user device include type of device, host name on the network, whether it is the primary device or a secondary device, active (e.g. PDA, desktop) or passive (e.g. pen drives), time of last update, and technical details relating to interaction styles, display size and OS in use.

- **Goal:** Goal objects represent user goals for activities and track goal descriptions, key dates, status, progress and also relationships to activities, contacts and individual information items.
- **Location:** Each location object stores details about a physical or virtual location of relevance to the user's work, and includes details about its address (physical or virtual), location type, location significance to activities (e.g. home, work, leisure, study, travel), relationships with goals, contacts and high-level activities. Map objects store a specific map or layout for use with map views, and are distantly related to location objects.
- **Time period:** Time period objects track details for any significant user-specified time-frame, with details about recurring activities, special events and corresponding links to views and activities of interest.
- **Information item:** Each information item uniquely represents a single electronic document, image, sound file or other file in the user's information space. Details stored about information items include title, file details, author, thumbnails, annotations, sharing preferences, and information source. Information sources include web sites, libraries, databases and people. Properties tracked for information sources include name, location, availability, author notes (such as author, year), retrieval date, and permissions of use.
- **Workspace Item:** Workspace items include all the different objects that populate view workspaces, including information item references, markers and time markers (such as timeline histograms and time delineators). Details tracked for workspace items include type, colour, associated icon or thumbnail, creation time and display status.
 - **Information Item Reference:** Information item references are information item aliases associated with the various activities and views the information item was accessed for. They link back to the information item and as a consequence keep track of the item, along with presentation (e.g. colour-coding) and importantly view coordinate information.

- **Marker Item:** Marker items include workspace notes, keyword anchors, diagrams, action icons and symbols. Item properties include their type, their colour, their textual contents (e.g. in the form of annotations for keyword anchors and action markers), their association (e.g. to the workspace, to a particular item) and their coordinates.
- **FlexView and FlexView Data:** FlexViews (both pre-set, simple and user-specified advanced views) and their corresponding FlexView Data objects are view objects tracked and saved by the information collection. The section on interface objects provides more information on them and their properties.

B.1.2 COMMUNICATION OBJECTS

Communications related classes in InfoMesh are given in Figure B-2. They include a session object, client and server objects, and a generic communication object.

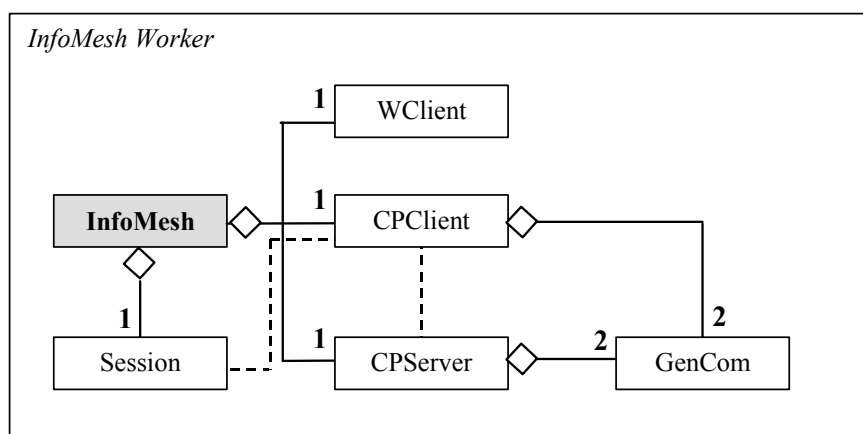


Figure B-2: Communication object relationships

- **WClient:** The InfoMesh Worker client communicates with the VC++ worker application and processes communications relating to information use (based on file changes in monitored directories). The VC++ application is located on the same device as the device's InfoMesh application (which is running the client). Messages received from the VC++ application are in textual format.
- **CPClient:** The InfoMesh (Composer-Presenter) client on any secondary device communicates with the InfoMesh server (CPServer) located on the default main device that contains the user's information repository. The client contacts the server at the start of the session to download the latest details and at the end of the session sends along its own updated details to the server.

Messages are sent and received as objects, potentially containing text file and other document attachments.

- **CPServer:** The InfoMesh (Composer-Presenter) server communicates with the InfoMesh client on secondary devices, passing and receiving updated details about the information collection. The server is only functional on the user's default main device containing the information repository. Messages are sent and received in object format containing file attachments when necessary.
- **GenCom:** The general communication object is used to send and receive information by the InfoMesh (Composer-Presenter) server and client objects. Its properties include details about the request or reply, the devices sending and receiving the information, a time-stamp, user verification details for security purposes, information space structure and representation details, and any necessary file attachments (i.e. any information items such as documents, images and other media that needs to be downloaded by secondary devices or uploaded to the information repository).
- **Session:** Session objects are used to manage information requests and details of changes to the information space on any single device in-between communications with the main device and central repository. It assesses the information that needs to be downloaded onto the device at the start of the session and tracks the information that needs to be updated to the central repository at the end of the session, initiating the required communications through the InfoMesh client.

B.1.3 WORKER OBJECTS

Worker objects in InfoMesh (see Figure B-3) are in part implemented as part of the VC++ worker application, with the remainder implemented as part of the Java InfoMesh application.

The VC++ application's objects include a server, a directory watcher, directory information, file notification details, file information and file change information objects. These objects largely stem from a previous implementation for TimeSpace (Krishnan, 2003), and have been modified and expanded to run on multiple devices (including PDAs) and to monitor several specified folders. The VC++ worker application runs alongside InfoMesh on each user device, in a

device-appropriate manner. The Java InfoMesh application's worker objects include a utility object, a web history watcher, an activity snap generator, and a data collection object.

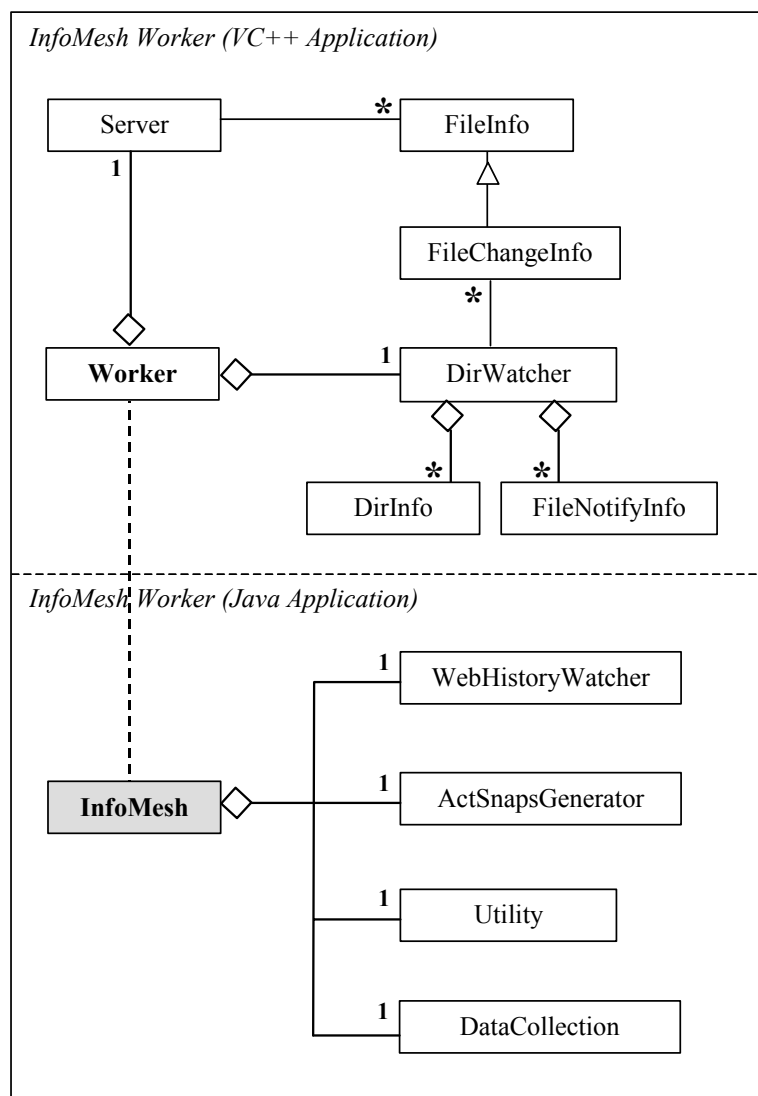


Figure B-3: Worker object relationships

The VC++ worker application manages a server connection to listen for requests from the InfoMesh Worker client and manages the connection to this client. Client requests often pertain to retrieving file details and preview thumbnails. The directory watcher object monitors the selected folders on the user device for file changes, to cover general file usage, bookmark creation and web browsing. The server notifies the InfoMesh Worker client of these changes as they occur, which helps track information use by the user.

The Java InfoMesh application takes care of other utility functions, such as generating splash screens, opening files and web pages from views and performing time and date calculations necessary for various view content and information synchronisation. When the worker signals web browsing activity, the web history watcher simply extracts relevant browsing details using Nirsoft's IEHistoryView utility (www.nirsoft.net/utils/iehv.html). (The tool is used to generate an up-to-date file of visited URLs using the web history file on a device, which is then used to extract the tracked URLs. Browsing using Mozilla web browsers can be tracked by incorporating the similar MozillaHistoryView utility.) Finally, InfoMesh also makes use of an activity snap generator, which structures and displays basic contextual views from several activity snap listings provided as textual data files in the application's data folder. The data collection object was designed for managing remote evaluation and data capture for a future long-term study of InfoMesh use.

B.1.4 INTERFACE OBJECTS

Interface objects in InfoMesh include various FlexViews, application dialogs, view pockets and nodes, as well as FlexTools components and settings. Figure B-4 presents a slightly simplified object model for InfoMesh Presenter classes.

InfoMesh can display several kinds of views, which can be pre-set views (e.g. Notice Board, Overview), simple context views (e.g. Activity, Social and Map views), and advanced views. The underlying view data is largely encapsulated in FlexView Data objects. All InfoMesh application dialogs and context-menus are chiefly managed through the InfoMesh application and FlexView classes.

- **FlexView:** FlexViews are the high-level InfoMesh view, geared towards device capabilities. They incorporate a generic FlexViews GUI set-up with view event handling and data storage for the information tracked for the particular view. View properties include view name, base activities and contexts, display parameters, a Birds Eye View for providing overview widgets, and FlexTools and FlexView Data objects. FlexView is the parent class for a variety of views that the object model depicts in simplified form: pre-set views (overview, work view, notice board), simple views (activity, social and map views), and advanced views (advanced activity, social and map

views). Each of these groups of views carry tailored display procedures to match the underlying view type and context.

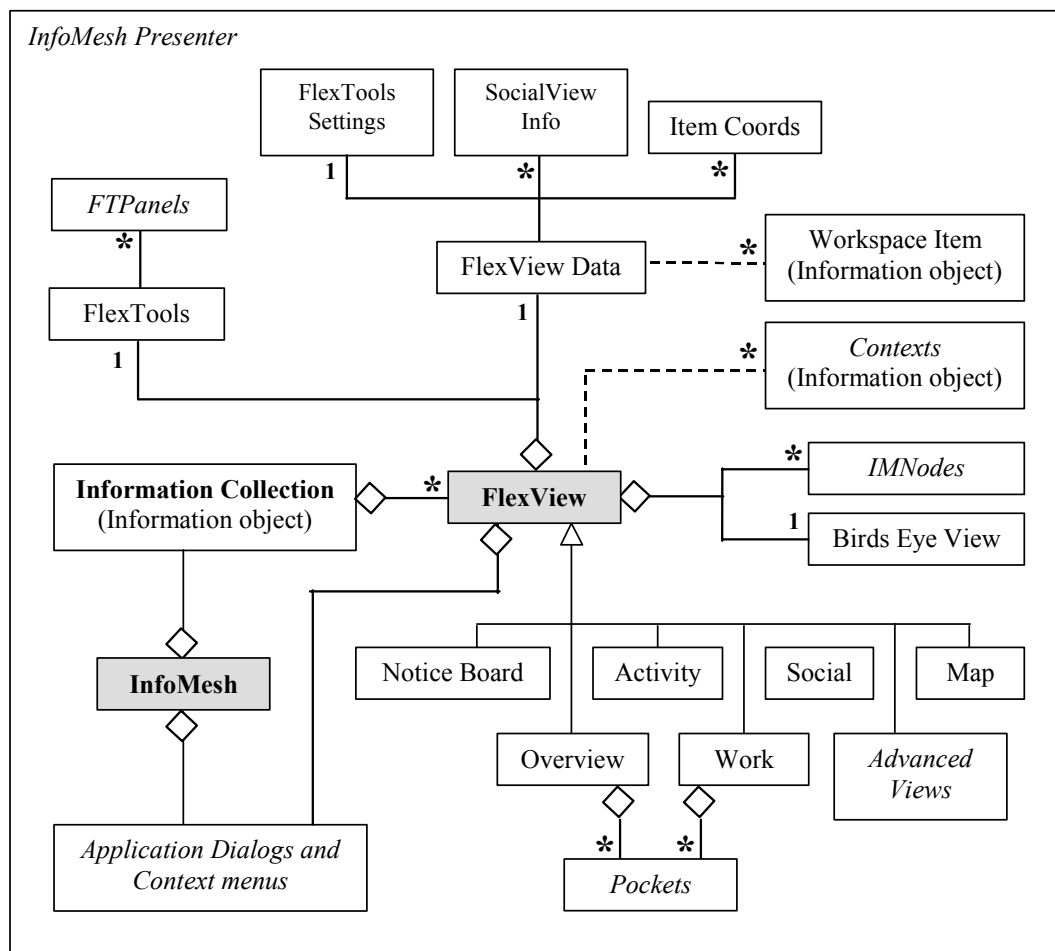


Figure B-4: Interface object relationships

- FlexView Data: FlexView Data objects manage all the view data and options for FlexViews. Pre-set views and advanced views each have their own FlexView Data object. Simple views based on the same underlying activity however share a FlexView Data object. FlexView Data objects are seen as interface objects even though they are stored persistently. These data objects track collections of the view's workspace items (e.g. information item references, marker items), contacts (including shared item details for social views), and relevant coordinates. Specifically, FlexView Data also tracks view-related FlexTools settings as altered by the user (e.g. display, view contexts, query and filter settings), which are applied to the view when the view is (re-) generated. The decision to use FlexView Data objects occurred after much deliberation. Several alternative solutions were written out and

some tested to develop the most efficient way of storing data to support multiple contexts and coordinate spaces, view swapping for the same underlying activity, memorising filter and query settings, and flexibly manipulating advanced views.

- **FlexTools:** As part of a FlexView, the FlexTools object manages all the visual components and options encompassing annotations, view markers, display, view contexts, filter and query, settings and preference details. The visual components are managed through FTPanels, the parent class for all of the FlexTools panels.
- **IMNode:** The InfoMesh node is the parent node for presenting objects (specifically the different workspace items) and manipulating them on InfoMesh view canvases. There are sub-classes for user, item, marker and overview timeline nodes among others. InfoMesh nodes use the underlying item display and coordinate details to generate items on the FlexViews, with transient storage for the display settings applied when the view is open. FlexViews are generated by populating the view workspace with the relevant InfoMesh nodes.
- **Pockets:** Finally, pockets are simple list views used by the overview and work view to give access to a summarised listing of recent items for an activity. Their properties include a title and a collection of workspace items (specifically information item references), and can be of the form of generic pockets or specific view pockets.

The PDA classes largely correspond with the desktop classes, except with respect to the interface classes. The PDA InfoMesh Presenter currently supports a basic FlexView object that provides display procedures for all the views, with a supporting Data object to store view details. In the current implementation, InfoMesh views are saved as images at the end of user sessions on desktops and laptops. On PDA synchronisation, these view images are transferred to the PDA's InfoMesh application for display on the device.

B.1.5 APPLICATION PACKAGE HIERARCHY

InfoMesh classes (as associated with the Java application) are stored in several logical packages, according to their function and use. Figure B-5 shows the

package hierarchy for InfoMesh (the highest level package is nz.ac.waikato.cs.infomesh). All classes from the Info package and specific classes from the View package are persistent.

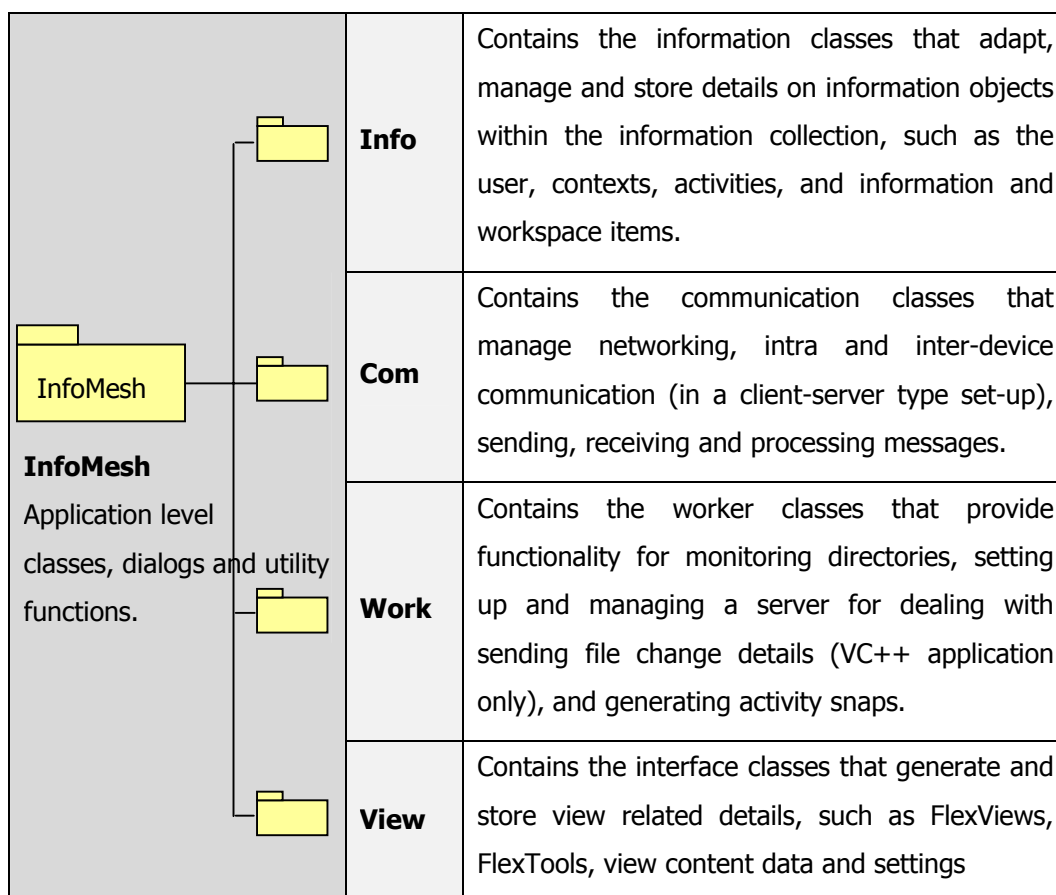


Figure B-5: Application Packages

B.2 APPLICATION PROCEDURES, INFORMATION AND COMMUNICATION

As described in the design process for InfoMesh (in 5.3.3), the final details requiring design and implementation focused on operational procedures; registering, processing and storing application information; and communication protocols and procedures. This section summarises these processes, which combine and streamline InfoMesh functionality for managing and seamlessly collating information use on multiple devices. In performing these wide-ranging functions, InfoMesh builds on the increasing processing power, vaster storage capabilities, and improved and faster connectivity available for devices.

B.2.1 OPERATIONAL PROCEDURES AND RESTRICTIONS

In developing InfoMesh, specific attention needed to be paid to the design and ordering of the various operational processes and corresponding protocols, and to the assumptions, restrictions and issues underlying InfoMesh function.

PROCEDURES

Operational processes in InfoMesh include tasks like starting up and closing InfoMesh, beginning and ending a device session, registering information, generating a view and so on. The following tables summarise some of the main InfoMesh processes with details of their functional design. Table B-1 presents details about the general operational processes, whereas Table B-2 and Table B-3 expand on the processes at InfoMesh start-up and termination.

General operational processes	
Process	Functional Design
InfoMesh first start-up	<p><i>Collected information:</i> user and device identification and details, default or secondary device status, and default settings for monitoring and registering information, storage and views.</p> <p><i>Tasks:</i> Start up InfoMesh applications; start session and open network connections; initialise information structure (Composer on primary device), load information from information repository (Composer on secondary device); start monitoring and registering information; generate start-up views.</p>
InfoMesh start-up	<p><i>Collected information:</i> username and password.</p> <p><i>Tasks:</i> Start up InfoMesh applications; verify user; start session and open network connections; load information from serialised files (Composer on primary device), download information from information repository (Composer on secondary device); start monitoring and registering information; generate start-up views.</p>
InfoMesh termination	<p><i>Tasks:</i> Close views; terminate automated tasks, assess session-based updates to information space; upload and save information to information repository (Composer on secondary device), save information to serialised files (Composer on primary device); close network connections and end session;</p>

	terminate InfoMesh applications.
Automated processes for information collection	<p><i>Collected information:</i> Details of files created or altered; web pages visited; contextual details such as timestamps, devices in use, locations of use (e.g. home, work), other people involved (e.g. shared documents), and activities in use.</p> <p><i>Tasks:</i> Monitoring selected user folders for change; tracking web browsing activity; registering contextual details related to the files used and the user's work context; requesting contextual details from the user when required; tracking user activities.</p>
Processing and storing collected information	<p><i>Tasks:</i> Create information objects to match activities, views, collected and user-provided details; add information objects to the information repository structure; update information objects with contextual details as these are registered; relate information objects to one another in the repository according to tracked details; store information for persistence by serialising information objects as text files, with structure and relationships intact.</p>
Intra and Inter-device communication	<p><i>Tasks (intra-device communication):</i> Receive messages from the VC++ worker application about document usage as it occurs, along with preview thumbnails of the documents and web pages.</p> <p><i>Tasks (inter-device communication):</i> Send and receive communications for downloading relevant segments of the information space from the information repository and updating changes to the information space to the repository. Communications are only accepted from and sent to verified devices, carrying valid user identification. Downloaded segments of the information space are adapted to the device capabilities and access settings before they are made available to the requesting device.</p>
Creating activities	<p><i>Collected information:</i> Details about the activity such as title, colour for colour coding, associated goals and so on.</p> <p><i>Tasks:</i> Generate an activity view for the created activity with the given details; track and present further file usage by the user as part of this activity.</p>
Generating and updating views	<p><i>Tasks (generating views):</i> Collect details about the new view or locate existing view; generate the blank view with FlexTools panels; gather all relevant information objects through the view data object; look up or generate coordinates for view items and place them on the view workspace; apply any</p>

	<p>previous FlexTools settings; match FlexTools panel options to the saved settings; limit view options and functionality according to the device.</p> <p><i>Tasks (updating views):</i> Update the view with new content as file usage is registered and as the users add markers and notes to the view; apply simple application intelligence in item placement; for simple views, update all associated contextual views with the new content and appropriate view placement coordinates; convert the view incrementally according to the FlexTools settings as the user updates view options.</p>
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Table B-1: General operational processes

Ordered processes for InfoMesh start-up	
Process	Details
InfoMesh start-up	Starts up InfoMesh Java-based Composer, Worker and Presenter, as well as the VC++ worker application.
User verification	User is verified using user name and password.
Session start-up	The session manager switches on. Communication lines are opened between InfoMesh and the VC++ worker application. A connection is set up with the main information repository if the current device is not the user's main device.
Loading information	<p>On secondary devices: A request is made from the Composer on the main device for necessary updates from the information repository. Composer processes the request, loads the serialized information files, extracts the relevant information, and sends segments of the information collection back.</p> <p>On all devices: InfoMesh loads the required details of the user's information space into working memory.</p>
Automated tasks	InfoMesh commences automated tasks of monitoring, registering, and communicating file usage and contextual information.
Generating views	InfoMesh generates and displays the start-up view, namely the overview, with supporting FlexTools options.

Table B-2: Ordered processes for InfoMesh start-up

Ordered processes for InfoMesh termination	
Process	Details
Closing views	InfoMesh saves final details from views and the (local) information repository state, and closes views.
Automated tasks	InfoMesh shuts of automated tasks of monitoring, registering, and communicating file usage and contextual information.
Session management	On secondary devices: The session manager collates the changes to the information collection for upload to the central repository.
Saving information	On secondary devices: The Composer linked with the information repository is sent a message with all the updated information from the user's information space. Composer processes the message, and integrates the details into the information repository.
Information persistence	The Composer on the main device stores the entire updated information structure as serialized text files, taking into account information objects and their relationships.
Session end	On secondary devices: Connections to the main Composer and the local worker application are closed.
InfoMesh termination	The Java-based InfoMesh application as well as the VC++ worker application are terminated.

Table B-3: Ordered processes for InfoMesh termination

Other processes not presented in detail here include swapping views, creating an advanced view, changing the underlying contexts for an advanced view, applying FlexTools settings, converting view data to view content, generating activity snaps and so on. Several main processes looked at briefly in this section are outlined in further detail in later sections.

FUNCTIONAL RESTRICTIONS

Both the size and complexity of InfoMesh as well as the time frame available for developing and evaluating a prototype, necessitated restricting the prototype functionality according to several assumptions and guidelines. Some of these assumptions and restrictions are as follows:

- Inter-device communication and information transfer occurs across a network for desktop and laptop devices, and at the time of synchronisation with a

desktop for a PDA. Furthermore, for prototype implementation and testing, a continuously available network connection is assumed for desktops and laptops.

- The first device that a user runs InfoMesh on is seen as the primary device and will carry the user's complete information repository. This device needs to be on with InfoMesh running when any other device is used, so that device updates can occur to and from the information repository. (Currently InfoMesh, for purposes of simplicity, does not allow users to change the default device once the system has been installed).
- InfoMesh only monitors files created or modified by the user, due to Windows XP limitations on successfully registering files that are simply accessed by the user. InfoMesh registers general information media used by the user, including regular textual and office files (e.g. text, Word, spreadsheet, PDF and presentation files), bookmarks, web pages, and image, audio and video files, but does not monitor email or calendar-based data at this point.
- An initial assumption is made that all of the user's personal devices are in the same time zone, and show accurate, synchronised times. A further assumption is made that users have not given dissimilar files the same filenames, when they are in the same folder in the hierarchy, but on different devices.
- An assumption is made that though the user may have multiple devices switched on, the user will only have one device active (i.e. the user only uses one device) during a single session, before moving to another one. Consequently, session based synchronisation of the information repository occurs in a linear fashion, with only a single device using and updating the repository at a time. This restriction helps decrease prototyping complexity by reducing synchronisation issues and simplifying testing and user evaluation.

Previous chapters have discussed some of the issues in developing Pervasive Personal Information Spaces. A few further specific issues in implementing and running InfoMesh are also worth noting here, as they would create problems with InfoMesh running properly. They include:

- Issues with file synchronisation, including for example user update of documents (modification, deletion, moving and so forth) while InfoMesh is switched off, starting and completing sessions without session-based

synchronisation (e.g. due to a missing network connection), and leaving files open on a device while another device is activated for use. These cause both problems in synchronising files across devices as well as keeping the information repository current and complete.

- Available device connectivity, including poor and failed network connections which can cause sessions to be started and completed without session-based synchronisation or affect how much and how fast information can be transferred. These problems can slow down work or lead to an incomplete information repository and loss of work updates.
- Integrating existing documents into the information repository. At first use of InfoMesh, the user most likely has numerous documents in their information space that have to be incorporated into the information repository for it to be complete. As a new device is added to InfoMesh, all the documents on the device can potentially be uploaded to the information repository. Issues here are that this process can take a while, integrating documents from several devices can cause problems if folder hierarchies are dissimilar or different files have similar names and locations, and that these documents will be in the information repository without activity or context data to support InfoMesh views.
- Application intelligence. InfoMesh currently only employs simple instances of application intelligence, including tracking user interaction history and registering basic work context, and calculating how to add and position information items on views. The techniques used are simple, and may therefore make incorrect judgements, requiring correction by the user.

These various assumptions, restrictions and issues invariably affect InfoMesh functionality, robustness and long-term use. However, for a prototype version, limiting scope and functionality for adequate implementation and evaluation within a set time frame was necessary. Especially as the main goal was to test the research hypothesis, explore and answer the research questions, and provide a useful framework for developing and exploring “Pervasive Information Spaces” for personal and public information collections.

B.2.2 MONITORING AND REGISTERING APPLICATION INFORMATION

InfoMesh applies several automated processes for monitoring and collecting data related to user work. These continuous processes involve monitoring file usage, tracking user activities and web browsing, and registering contextual details (carried out primarily by the directory watcher and context monitor agents). Users can use FlexTools options to set how and when these automated processes run; though currently the options are not fully implemented.

The initial difficulty in applying these processes lay in what information should be gathered in tracking user activities, and consequently how to implement the functionality. Information is gathered at four levels of system operation:

1. InfoMesh system level (Composer with repository, primary device)
2. Device and InfoMesh application level (Worker-Presenter, all devices)
3. Activity and view level
4. Information item level

Table B-4 presents the information gathered at these four levels (indicated by specifying the level number(s)) by separating out information that is monitored and tracked, registered, collected and generated.

Information gathered at the four levels of system operation	
Monitor and Track	<p>(2) File usage, by monitoring selected user folders on the device for files created or modified.</p> <p>(2) Web activity, by tracking web history and the bookmarks' folders, for user web browsing trails, web pages visited and bookmarks created.</p> <p>(2) User activities created and used (e.g. created, opened, closed, switched to).</p> <p>(2, 3) Limited user interaction and action history.</p>
Register	<p>(2) Device details (device context), such as device identity, host name, type, connectivity, settings and capabilities, as well as connectivity status of secondary devices.</p> <p>(2) Standard details for files used (created or modified). Details include title, location, type, size and timestamps.</p> <p>(3) Contextual details for activities and views, such as information items and markers, timestamps, devices in use, locations of use if</p>

	<p>specified by the user, other people involved (e.g. for group activities), and significant events.</p> <p>(4) Contextual details for files, such as timestamps, activities the file is a part of, information source (e.g. a database or the Internet, with location), and other people involved (e.g. authors of documents).</p>
Collect	<p>(1, 2) User identity and verification details, such as username and login information.</p> <p>(1, 2) InfoMesh settings and preferences, including system, access, privacy and security settings.</p> <p>(2) Device details such as user-given name for the device, device-preferred activities and interest categories.</p> <p>(3) Descriptive details for activities, such as activity title, description, colour coding, interest category, annotations and goals, status, user group and member details for team activities, related activities and actions, access settings and preferences, locations of use if specified by the user, and important events and dates.</p> <p>(3) Details for views, such as action markers and related annotations and keywords, workspace notes, altered coordinate details for view content, underlying maps, view settings and preferences (through FlexTools and according to device), and view annotations.</p> <p>(4) Details for information items provided by the user, such as annotations, colour coding, action markers, altered placement coordinates through item arrangement, priority indication, information source, location of use, shared status and other user-specified contextual information.</p>
Generate	<p>(1) A user profile and model (potential simple implementation), from information captured about activity use, interaction and action history, and user preferences.</p> <p>(2) A device use profile (potential simple implementation), from activity use and interaction preferences.</p> <p>(3) Details for activities and views, such as underlying templates and maps, levels of activity use (e.g. based on frequency of use or documents accessed), activity history, view content, social networks, activity and view link-up, and references to relevant files and markers.</p> <p>(4) Details for information items, such as timestamps, document preview thumbnails, item use frequency and coordinate information for views.</p>

Table B-4: Information gathered at levels 1 to 4 of system operation

Previous sections on system architecture and application classes provided a first look at the implementation details for gathering information in InfoMesh. Table B-5 now collates and summarises the techniques used to gather information, by once again looking at information monitoring, tracking, registering, collecting and generating separately.

Information gathering techniques	
Monitor	Watching selected directories (including bookmark and Internet cache folders) for file change messages issued for created and modified files.
Track	<p>Monitoring web history files for updates (using a separate utility) and gleaning details from these files about the web pages visited since the last update.</p> <p>Tracking user activities as they are created, opened, and switched to another. Similarly, keeping a list of all major user interactions (such as opening views, creating new views for existing activities and changing manipulating view settings). Together these details form a history of user interaction.</p>
Register	<p>Windows is queried for device details at the start of a session, as well as file details for files created or modified by the user.</p> <p>As users use documents and add action markers to views, these details along with time, device, annotations and social sharing information are registered and added to the current activity and/or view.</p> <p>Furthermore, when an existing file is used within the context of a particular activity or view, that file reference is updated with a preview thumbnail, time, activity, source and contact details as applicable at the moment of use.</p> <p>Registered details are only those that the computing device has easy access to (e.g. device in use) or can be easily assumed or determined (e.g. time of use or URL for online information source). These then form a simple context for the work, which can be expanded with user-provided information.</p>
Collect	<p>Information is collected explicitly and implicitly throughout InfoMesh. At the start of InfoMesh use, the user is explicitly asked for his or her details for verifying use and access.</p> <p>Through FlexTools, dialogs and pop-up menus, users can further update options for settings and preferences, give a name to devices</p>

	in use, create and provide activity details, update contacts, and provide annotations, colour coding and so on for activities, views and information items. In the view workspaces, the user can also change the content by re-arranging information items.
Generate	Information generated by InfoMesh usually occurs through separate procedures for taking screen captures (for creating document thumbnails), keeping track of file use to calculate frequency of file and activity use, calculating view coordinates according to view templates for new activities and views, generating view content from the underlying data and so on.

Table B-5: Information gathering techniques

B.2.3 PROCESSING APPLICATION INFORMATION

Once information has been tracked, registered and collected, InfoMesh needs to process the details, which occurs largely through the logical and visual information organiser agents. Processing involves collating, associating and adapting information according to InfoMesh's information model, and device and view requirements for representing that information. Steps in processing information include:

1. Creating information objects for the new files created, file references, activities, views and contexts (e.g. contacts, devices, and maps/locations).
2. Adding information objects to the information structure and repository.
3. Updating existing information objects and information relationships with registered and collected information. For example linking context and information item objects, and adding contextual and supporting details like sources and annotations to information objects.
4. Creating and updating information relationships by integrating information item objects with one another and with view and activity objects (for example when an existing item is accessed as part of a new activity and associated views).
5. Updating view properties according to changes in the FlexTools settings.
6. Integrating information use on several devices together. For example: comparing, creating and updating information objects, activities, views, settings and information relationships.

7. Adapting information representation and view detail to the local device, according to device capabilities. This can involve sending and presenting only selected segments of the information space, selected documents, document summaries or item extracts, just title and thumbnail information instead of entire document sets, or only view images for smaller devices like PDAs.

B.2.4 STORAGE OF APPLICATION INFORMATION

As InfoMesh maintains a detailed information structure, and gathers and processes large amounts of information, appropriate storage and access to this information is necessary. This section looks at what information is stored, how and where.

A previous section on information object models has indicated how information is structured in InfoMesh. Information stored by InfoMesh utilises this structure, with its relationships and detail. Though some data collected and processed is temporary, or transformed or integrated into other information objects, InfoMesh ultimately makes use of several kinds of information storage, namely:

- *Internal storage of InfoMesh information structure, content and representation for operational use:* system level details for information objects, including activities, views and view data, information item objects and annotations, user details, contexts, settings and preferences, interaction history, formats and protocols. This system level information is available on both main and secondary device applications locally, and is implemented and accessible as inter-linked instances of information and interface classes. Of the actual electronic information items (e.g. documents and images), the secondary devices only store those required by the user for the session.
- *Internal storage of session-based details:* application level details pertinent to the current session on the device in use, which includes details communicated to and from the information repository, file change notifications from the worker application, session-based calculations of changes to the information collection and interaction history for the duration of the session. These details are largely implemented and accessible as instances of the relevant communication and worker classes, created and destroyed within a session.
- *Persistent storage of information structure and content:* repository information and representation details relating to information objects,

including information items, activities, views, contexts, settings, user and devices. This information set largely mirrors the information structure and details stored internally for InfoMesh operational use. Information objects are serialised to files using Java's serialisation mechanism and format. They are serialised either separately or as part of a hierarchy or relationship according to the information object model. Each information class has its own file at present.

- *External storage of application data:* application data that incorporates utility tools, serialised files for persistent storage of information objects, activity snap data listings for activity snap generation, help documentation, information item preview thumbnails, InfoMesh images (including application and marker icons, maps, PDA views, contact photos), temporary files and files for session-based updates and downloads. The application data folder is part of the InfoMesh installation and used on all devices.
- *Archive storage of information repository:* combined details of information stored for persistence, key application data and underlying monitored folder content of information items, such as images, documents, web pages, video and audio. These details are in part serialised as text files and in part stored as information items, in an appropriate hierarchy of folders for easy retrieval and back up to external or mobile storage devices.

In developing InfoMesh, various options were considered for managing information storage of files, especially with respect to local storage of information and storage on a data server maintaining a complete information repository. These options included:

1. Providing only local storage for information items, where all actual documents are stored on the local device they are used on, with the data server storing only the information structure and representational details. This option unnecessarily requires secondary devices to communicate with one another as well as the data server and repository to retrieve documents.
2. Mirroring local storage and the data repository, so that both have a complete structure, representation and file content. This option was considered only theoretically, as only larger devices could store the entire information

repository, and as information transfers and updates would become very cumbersome with this set-up.

3. Providing a local storage that only stores files requested by the user at any given time or other temporarily necessary files. In this set-up, the local storage is minimal, with the main information repository containing the entire information space structure and content. Local files though may be used more on the local device than any other, creating a disadvantage. Furthermore, this option relies heavily on a fast and continuous network connection, so that necessary documents can be downloaded and uploaded according to use.
4. Allowing local storage to keep local files and documents retrieved for temporary, session-based use, while the information repository retains all documents along with the representational details. InfoMesh further downloads the entire information structure and representational details onto the local device for session-based use. Device views are biased towards the documents used by the user in a session, which also find their place into the local storage. At the end of a session, files of temporary interest to the user are deleted from the local storage to create space.

Option 4 was selected as the best option and implemented in the InfoMesh prototype. A future implementation idea involved developing the previously mentioned Beamer, a small wearable device carrying the entire information repository: structure, representation and content. The Beamer can be carried everywhere and can transmit recent activities and views to any device the user then interacts with. The user can download any documents or further detail as required from the Beamer through InfoMesh view interaction.

Early on in the research, several options were considered and studied for persistent storage, including the RDF format (www.w3.org/RDF/), separate relational databases (such as an SQL database) and serialisation of information objects into files, with structure and relationships intact. In the end, object serialisation was opted for in the prototyping phase for several reasons:

1. The existing information structure and objects in the application could be used, stored and read directly, more readily than when using a separate format for storage only, and

2. Serialised files could be transferred selectively and quickly between devices compared to single, large databases.

A full system implementation of InfoMesh may require further consideration of storage formats, but for the prototyping phase, object serialisation seemed both an appropriate and straightforward option.

B.2.5 COMMUNICATION PROCESSES AND PROTOCOLS

InfoMesh employs intra and inter-device communication processes to keep all devices and the user's information repository updated according to user interaction and activity. These processes involve various protocols for managing information requests and transfer, device sessions and connectivity, as well as considerations for transmission security and privacy.

INTRA-DEVICE COMMUNICATION

Intra-device communication in InfoMesh occurs between the VC++ worker application and the Java InfoMesh application on each device, and commences at start-up. As the worker application monitors and registers file usage in selected folders on the device, the application passes along these details to the Java application. As both applications are on the same device, there are no imposed security or privacy checks.

Communicated messages are formatted to contain details of the file change along with supporting file details. The generic format of the message includes the message type (e.g. file change, file info), file type (e.g. file, bookmark, web page), file change type (e.g. created, deleted), and relevant file details (e.g. file name, path and path to the created preview thumbnail). Currently the only type of message the worker application is required to send is a file change. The changes that the worker application registers include file creation, deletion, move, modification, access and renaming, though access is only registered in a limited manner. The file change messages sent out by the worker application are:

```
FILECHANGE FILETYPE CREATED filename path thumbpath
FILECHANGE FILETYPE DELETED filename path
FILECHANGE FILETYPE MOVED filename oldpath newpath
FILECHANGE FILETYPE MODIFIED filename path thumbpath
FILECHANGE FILETYPE ACCESSED filename path
```



```
FILECHANGE FILETYPE RENAMED oldfilename oldpath  
newfilename newpath
```

SESSION-BASED INTER-DEVICE COMMUNICATION

Inter-device communication in InfoMesh occurs between the Java Composer server on the main device containing the information repository, and the Java Worker client on a secondary device. The session manager (Session object) on the client-side regulates the client's requests, as well as details about the information upload and download.

Information transferred is in the form of communication objects, namely instances of the class GenCom, using object serialisation across the network. According to the information requested and received, GenCom objects can contain numerous details and flags about the message request or reply itself, requesting device and user verification details, the information repository structure and representation details (including user settings and preferences), as well as user files (such as documents and images). User files are currently sent across using a simplified version of the File Transfer Protocol.

Options considered for inter-device communication in the design process included the following:

1. Offline information transfer through small, mobile storage devices (such as pen drives).
2. Information transfer across a wired or wireless network for desktop and laptop devices, and at the time of synchronisation for PDAs.
3. Information transfer across a wired or wireless network for all devices.
4. Information transfer across a WPAN using an active, wearable device (such as the Beamer device mentioned in Appendix B).

InfoMesh currently implements option 2. Option 4 can be considered for the near future, offering a real-world solution that can support privacy and security well, and manage larger amounts of data without too great a dependency on connectivity.

InfoMesh applies various protocols for inter-device communication, according to the type of requests or communications made.

1. At the start of a session, the client device will request to download information space details and documents for the user session, according to the device criteria.
2. At the end of a session, the client device will send the updated information space details and documents created or modified during the session back to the server for update to the information repository.
3. During a session, the client device can potentially request to download documents, document summaries or entire activity or view content (i.e. all information items belonging to an activity or view) from the information repository according to the user's request.

For desktops and laptops, the client-server connection is currently established at the start of a session and closed at the end of a device session. Once a device has connected to the server, the server registers that a session is in progress and will only accept another device connection once the first session has been completed.

Only requests and communications of type 1 and 2 occur for PDAs, as these devices currently only connect to the information repository at the time of synchronisation. Extending the PDA version of InfoMesh to establish and close connections across a wireless network is straightforward. The limitation currently lies in the ensuing slow speed of information transfer for a PDA performing session-based synchronisation wirelessly.

Tables A-8 to A-10 now present the InfoMesh protocols for the three types of session communications. The protocols are presented here in their simplified form, assuming successful connection and communication between registered user devices.

(Protocol A) Session start – Information download protocol	
Client	Server
1. Client calculates or requests details from the user about the documents to download (Session Document Download dialog). 2. Client connects to the Server.	3. Server accepts connection and flags that the session is in progress

<p>4. Client sends a GenCom object with device id, user details and request.</p> <p>9. Client accepts and processes information received, by</p> <p>a) loading information space details into the application information structure, and</p> <p>b) loading documents into local storage, and updating the local folder hierarchy as necessary.</p> <p>10. Client sends confirmation of message receipt.</p>	<p>5. Server accepts GenCom object.</p> <p>6. Server verifies user details and checks if the device connecting is a new addition, to update device details accordingly.</p> <p>7. Server processes request, identifying request type, device, device settings and time of last update for the device, to determine the reply to be made.</p> <p>8. Server collates and returns a GenCom object reply, containing the information space representation details and requested documents.</p> <p>11. Server accepts confirmation and awaits further requests.</p>
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Table B-6: Information download protocol at start of session

(Protocol B) Session end – Information upload protocol	
Client	Server
<p>1. Client determines details to be uploaded to the information repository.</p> <p>2. Client sends a GenCom object update request, containing updated information space details, all created or modified documents with path information, and all file change messages received from the worker for the session.</p>	

<p>5. Accepts confirmation, closes connection and deletes any temporary files.</p>	<p>3. Server accepts and processes the GenCom object, by</p> <ul style="list-style-type: none"> a) creating a backup of the old information space details, b) processing the relevant file change messages received in order (with respect to file move, deletion and renaming), c) updating the information structure with the new details, and d) adding the documents to the information repository at the appropriate locations. <p>4. Server sends a confirmation receipt to the client, closes connection, re-sets session to none in progress, and awaits further device connections.</p>
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Table B-7: Information upload protocol at end of session

(Protocol C) During the session – Information request protocol	
Client	Server
<p>1. If the user opens an activity or view with content that has not been downloaded, or opens a document on a view, the client asks the user whether relevant documents or document summaries need to be downloaded (Download Documents dialog).</p> <p>2. Client sends a GenCom object with an information download request, containing the documents or document summaries to be sent (indicating the activity or view, or document path as necessary).</p>	<p>3. Server accepts and processes the GenCom object.</p> <p>4. Server collates and returns a GenCom object reply, containing the requested</p>

<p>5. Client accepts and processes information received, by adding the documents to the local storage according to their given path, and opening any documents requested by the user.</p> <p>6. Client sends confirmation of message receipt.</p>	<p>documents or document summaries.</p> <p>7. Server accepts confirmation and awaits further requests.</p>
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Table B-8: Information request protocol during a session

There is a further protocol relating to the start-up and function of the InfoMesh server (CPServer), client (CPClient) and session manager (Session) objects according to the device they reside on, as all InfoMesh versions are similar in their set-up but vary in their functionality according to device.

- The server is only functional and awaiting client connections on the user’s main device.
- The session manager and the client on the main device are never activated. All updates on the main device occur directly to the information repository.
- The session manager and client are only activated on secondary devices.
- The session manager on secondary devices keeps a list of the user’s interaction history and all file changes registered by the VC++ worker application during the session for update to the information repository. Further specific details are stored about the files created or modified in the session.

The privacy settings applied to InfoMesh inter-device communication currently involve only user verification, by verifying username and password during communications. Transmission encryption was also considered to keep communications secure. The encryption functionality provided by the Java Cryptography Extension (JSE) to the Java Cryptography Architecture (JCA) seemed appropriate for InfoMesh communications, specifically symmetric stream encryption (RC4). However, at this stage communication encryption and decryption have not been explored in detail or implemented.

C. INFOMESH EVALUATION DETAILS

InfoMesh user evaluation consisted of two short-term user studies on InfoMesh and a preliminary investigation into InfoMesh long-term use, as described in chapters 6 and 7. Long-term evaluation of InfoMesh was considered in-depth during the research work. Section 7.3 of the thesis enumerated the reasons why a full longitudinal evaluation fell outside the scope of the research work. This section first tabulates key findings from the first two user studies for reference. Then the section presents the study plan for a long-term study (emphasising desktop use of InfoMesh) and a reflection on InfoMesh long-term use based on a preliminary pilot study by the author. The section concludes by describing short and long-term recommendations for InfoMesh development for exploring and investigating Pervasive Personal Information Spaces further, based on the findings from the different studies carried out on InfoMesh.

C.1 SUMMARISED FINDINGS FOR INFOMESH USER STUDIES

Tables C-1 and C-2 summarise the findings for the first study on InfoMesh visualisations and the second study on InfoMesh visualisation, interaction and use, for easy review of the studies' key findings.

Study on InfoMesh visualisations: Key findings summarised
Background questionnaire
Multiple devices were used on a day-to-day basis. More than one device is used for certain activities, whereas some other activities were carried out only on a specific device. Activities varied significantly between participants.
The goal of synchronising information was to provide access to working documents and to back up information. Documents were largely stored in structured folders, with some stored online.
Information synchronisation largely occurred through network connections, email and USB storage devices. Information synchronised largely involved current work and important documents that were backed up. Some information was never shared with other devices.

Document relationships were largely shown through folder classification and folder naming schemes (including date, location, time, goal or metadata information). Occasionally file aliases and copies, and embedded links to related information were also used.

Work context was specified only in a basic way, using naming schemes, adding useful details to the actual document, keeping separate files for tracking contextual details for a set of files, and occasionally with personally developed systems and strategies.

Tracking work details was largely done manually, with to-do lists on a file, through email or on paper. As with user activities, information management activities also varied with the individual according to their habits and preferences for certain methods.

Physical information spaces were often annotated through the use of notice boards, post-its, coloured stickers and colour coded binders or folders for tracking notes, marking information of interest, archiving information, and relating and categorising documents.

Electronic workspaces and information were less actively annotated. Participants used naming schemes, desktop placement of items, embedded links and virtual desktops to mark and annotate their space.

Introduction to Pervasive Personal Information Spaces and InfoMesh

Participants understood and supported the research concept, especially as it reflected how people natural think and interact, and shifted interaction away from information management to support actual activity.

In the InfoMesh demo, participants noted the multiple, contextual views and features like colour coding, annotating documents and workspaces with notes and markers, switching tasks and contexts. These were singled out for their support of activity continuity, activity switching, contextual navigation and reminder functionality. Participant views on InfoMesh use were appreciative and ranged from full support for all uses to selective preference for certain views and aspects.

Exploratory tasks: InfoMesh desktop and PDA visualisations

Participants grasped most of the InfoMesh desktop views and view elements. They felt the views were useful to track work (with context), plan and share activities, interpret the work done, view progress made, identify document relationships, have a broad view of their information space, and quickly resume work and recent activities. They also felt that the views provided information for documents to aid future retrieval. The views would not be useful for activities like gaming and listening to music. Participants appreciated InfoMesh features for adding annotations, arranging and colour-coding information objects, with varying personal preferences as to their real-world application. Preferences for visual elements and presentation styles interestingly varied with participant, though all participants preferred the graphical social view to the textual alternative design.

Participants considered PDA views appropriately close to their corresponding desktop views, but not as quickly usable or useful as the desktop views. The map view was much liked as an overview for on the go, but the PDA views required simplification. PDA views were largely considered useful in specific contexts of use, such as for quick access to information when travelling or meeting with a group. The views had their use through simply their contextual representation even without the underlying documents.

Reviewing InfoMesh usability, specific (alternative) visualisations were preferred over others, such as the visualisations of the social and work views. Certain visual elements were valued enough from alternative designs for them to be incorporated into the selected views. More study is needed on the various overviews. Initially the number of views offered needs to be reduced, and important features also need to be refined and functioning correctly. PDA views need to be simplified and reduced in number. Presentation quality needs to be improved, with view content personalisation options available through FlexTools. Certain visual aspects required change (e.g. workspace notes, some icons). Participants also put forth a number of useful suggestions.

Participant perspectives on InfoMesh views emphasised the usefulness of the presented information relationships to user work, the graphical organisation and representation of information relationships according to contexts, the flexible interaction, and personalised annotations. The rich visual content and multiple perspectives were considered helpful in assimilating information and reminding them of their information space content. View use would vary though according to the individual, their work and their preferences. Views would be useful for various activities, as well as high-level access and interpretation of the information space, generating ideas. Participants thought that the desktop views would support them in creating, populating and accessing their information space, whereas the PDA views would help them with viewing, reviewing and reminding at a more conceptual level.

Comparative task: InfoMesh and hierarchical folder views

Strengths of hierarchical folder visualisations: clear file details, file sorting according to details, hierarchical view of documents, quick access to a file when its name and location were remembered. Weaknesses: names are the only true indicators for a file, no annotations or contextual or personalised details available, technical and detached from the user, little representation of information relationships, and not geared towards carrying out or making sense of work.

Strengths of InfoMesh: Visualisations relate items and support various annotations for easier access and interpretation of information according to the work context, functions on a semantic level, more practically useful for carrying out activities and showing items according to where they belonged, not tied to one location or device, and provides personalised access to information from anywhere. Weaknesses: no clear file details or file sorting, and expansive views may lengthen file access times.

The two systems were thought to complement each other well, because of the opposing weaknesses and strengths. Richer, more informative views of the document space were considered necessary, as they emphasised user work and work context.

Some participants preferred the InfoMesh views to the folder views for their work, others felt that they would use both as they complemented each other, with one participant with a stronger preference for the folder system. The use of PDA views for daily interaction was harder to gauge.

End of study questionnaire

Participants considered anywhere-anytime access to information through an integrated information space as one of the most useful aspects in reducing effort in synchronising information. In certain situations this was unnecessary. They appreciated automatic tracking and integration of documents, as long as they could control the tracking options. Participants also appreciated structuring information according to the work context using time, location, devices and people, as they felt that real world activities centred around these contexts. Contextual details enriched activity spaces, overviews acted as a reference for past and current work, and annotations were thought to help personalise and mark the information space according to user preferences.

The best thing about InfoMesh was its overall vision, its graphical representations and contextual detail, which revealed and highlighted information relationships. The most annoying thing included some overviews (according to each user preferences) and some aesthetic aspects of the visualisations. Views may also take some time to learn.

Participants felt that the ideas in InfoMesh would work because it reflected the user's natural way of thinking about and organising information, using contextual detail flexibly. Still, InfoMesh could be held back by several factors, such as user reluctance to adopt a new system, time to learn and use the system, complexity with multiple rich visualisations (especially on PDAs), and technical problems that were not ironed out.

Table C-1: InfoMesh visualisations study findings summarised (Phase I Evaluation)

Study on InfoMesh interaction and use: Key findings summarised

Background questionnaire

Participants interacted with multiple devices, including PC and Mac desktops and laptops, Internet tablets, PDAs and smartphones. Some participants designated certain devices specifically as work or personal devices. Others preferred one device for all their main information-interaction. This affected information distribution across devices, with some information or activities specific to a certain device, and others overlapping across multiple devices. Once again only important information was consciously shared between devices or backed up, even though participants would wish to back up their information more extensively and more frequently. Information on devices was related to a variety of activities. Web browsing activity involved both the lookup of transitory information and information for long-term use.

A close-up of user activities illustrated their unique and personal nature, and showed the tight relationship between activity content and context. Participants utilised a variety of techniques for tracking contextual information (a laborious and incomplete process), but most details were still only committed to memory (and easily forgotten).

Introduction to Pervasive Personal Information Spaces and InfoMesh

Participant impressions of Pervasive Personal Information Spaces and InfoMesh from reviewing the user guide were positive. Participants described the need for a visual tool that provided integrated access to their information space, and appreciated that it could help remember the finer details surrounding their work. Personal preferences guided participant interest and support of specific aspects illustrated through InfoMesh (e.g. specific contexts, overviews, information depicted visually, personal annotations).

Exploratory tasks: InfoMesh desktop and PDA prototype

Participants followed the meaning of the select views (specifically overview, activity view, social view and map view) and view elements readily, especially by interpreting them according to the underlying activity snaps, and the visual and contextual cues presented in the views. The various contexts were perceived as providing a relevant way to display and retrieve information, implicitly saying much about the underlying activity and information items. The visual context supported making inferences about the activity and making sense of it. Participant interpretation of the activity spaces also proved them useful for sharing information trails and archiving information. They were positive about having all their information and views accessible in consistent ways on all their devices, including PDAs.

The overview was seen as a starting point for (re)finding information geared towards their activities, aiding in tracking and revisiting work according to chronology and chronological activity relationships. The time context supported orienteering behaviour and reviewing work progress, and also offered an activity reminding function. Activity views were considered useful in tracking and reviewing work over time, resuming work, retrieving work according to contextual cues such as time and colour, associating different pieces of information in their activity space. Social views helped answer questions and retrieve various details about teamwork. Though the map view was much appreciated, location-oriented views would only be useful for specific activities (of which many examples were given), depending on user activities and preferences. PDA views were deemed useful on the go and in particular situations as in meetings for referring back to information.

Interestingly, all the views invited and encouraged easy exploration, comprehension and interpretation of the information and information space. Participants expressed interest in view flexibility and multiple contextual views on the same information, filter and query tools, and views that combined several contextual views as explored in early design ideas. Individuals again highlighted certain features (e.g. colour coding, use of markers) and interaction modes over others according to their work preferences and their own activities. Subtle user preferences also suggested alternative representations or details to encompass in some views (e.g. work flow representations in social views). User examples showed how InfoMesh focus was on the work process, the activity, contexts, all of which helped them interpret, infer and retrieve details about the work using more natural cues.

A number of issues surfaced include confusing naming schemes for views and some view elements, colour legends for activity views, toolbar access to activities and views, slower InfoMesh performance for map views on an older processor, added support in the social view for collaborative work.

Participant views were positive on view presentation and use, automated information synchronisation, work tracking, visualising work contextually using multiple views and personalised annotations, and anywhere-anytime access to information. The feeling was that InfoMesh contexts provided a softer, relative picture of information compared to the hierarchical folder system, appropriate for capturing work and work context, and supporting work interpretation and information sharing. Personal preferences influenced participant opinions on the practical use of different views and features.

Assessment tasks: InfoMesh interaction and use

Participants readily fell into using FlexTools and popup menus for creating annotations, adding markers, arranging and colour coding items, flagging items as important and so on. Some suggestions were given to improve this interaction. Participants however felt that the tools helped create, query and use rich views.

Participants readily took to creating and using multiple contextual views for the same activity. Switching between them, they were able to make inferences on the activity through its changing contexts, and were also able to use the different contexts and associations to remember and re-find information through an information orienteering process. The steps to switch between activities needs to be shortened however, through toolbar access for example.

Comparative task: InfoMesh and hierarchical folder views

Study findings supported the perceived strengths and weaknesses for InfoMesh and hierarchical folder views recorded in the first study. The main perception was that both systems offer different ways of organising information. Suggestions were made for integrating the two kinds of systems.

InfoMesh allowed users to glean information relationships according to location, time, people and annotations that could not be deduced from traditional hierarchical file managers. Graphical representations were also emphasised, especially as implicit and query-based retrieval was possible according to contexts and annotations. InfoMesh views were considered useful for a wide variety of professional and personal work, and for making sense of work. But InfoMesh could become visually too demanding with large, well-populated views, and can have more issues with privacy and security because of the large amounts of personal information related together.

Hierarchical folder views offered sortable lists of information, with expressly remembered documents easy to retrieve. However, they were considered static and lacking in contextual information.

End of study questionnaire

Participant views on the concepts underlying Pervasive Personal Information Spaces were again positive. Anytime-anywhere work-oriented computing was popular with participants, many of whom were interested in adopting a system like InfoMesh. Automatic tracking of work and device integration were deemed useful in reducing user effort. Network, privacy and security issues could however hamper system use. Different perspectives on the information space offered by flexible views were considered useful, especially for re-finding items and information orienteering. Annotations would allow participants to associate their ideas and notes with their activity space and work context directly, supporting easy information querying and reducing user effort in tracking down important content. An overview further provided a overview of the information space, a means to resume work, and a way to chronologically view work evolution and progress.

The best aspects of InfoMesh were its overview of work, the contextual views and the multiple perspectives they offered on information, the integrated and synchronised access to the information space, the ability to use various annotations, and the colourful visual and spatial representation of information. Annoying aspects of InfoMesh included potentially cluttered views with too much visual information to make sense of, manual entry of certain metadata, slower performance, and initial time required to learn the system.

Participants again felt that the ideas in InfoMesh would work because they reflected the way people think and work. Participants felt that the ideas in InfoMesh could be problematic due to cluttered views for larger activities, insufficient tracking of contextual data, differences in user work preferences, user reluctance to adopt a new system, and technical issues that might hinder InfoMesh daily use.

Table C-2: InfoMesh interaction and use study findings summarised (Phase II Evaluation)

C.2 STUDY PLAN FOR INFOMESH LONGITUDINAL FIELD STUDY

The following study plan has been drawn up for an initial investigation into the long-term use of InfoMesh, carried out predominantly on the InfoMesh desktop. The study focuses on select InfoMesh functionality and use over the course of two weeks, to assess how well users can understand and incorporate InfoMesh in everyday computer-supported activities.

The study incorporates a wide variety of instructional and evaluation tools, including tutorials, video demonstrations, exploratory and assessment tasks, subjective evaluation, interviews and questionnaires. In the following sections, the plan details the purpose and problem statements, participant profile, methodology, study environment, data collection and evaluation measures relating to the study.

C.2.1 PURPOSE AND PROBLEM STATEMENTS

The purpose of this study is to evaluate long-term real world use of InfoMesh and the interaction experience it offers users (focusing specifically on the desktop prototype). The goal would be to use the insights from the study towards assessing InfoMesh use and appropriateness, refining the interface design and interaction, assessing the usefulness and suitability of the conceptual model underlying the prototype and adapting the same as necessary.

The long-term study is designed to answer the following questions. Expanding on the previous user studies, answering these questions will help test the research hypothesis through real world use.

- How easily can users understand and embrace the concepts introduced by InfoMesh?
- How readily can users understand and employ the views presented by InfoMesh on the information space in support of their everyday computer-supported activities?
- How do users experience the interaction with InfoMesh?
- What are some of the performance and usability issues in the current InfoMesh prototype and prototype designs? What improvements would InfoMesh benefit from?
- How do InfoMesh flexible views on information compare to current hierarchical folder views?
- What are user views on Pervasive Personal Information Spaces (as presented by InfoMesh) and their use, especially in providing (ubiquitous) access to their electronic information and supporting high-level activities? How do users perceive their entire information-interaction experience with InfoMesh?

C.2.2 PARTICIPANT PROFILE

Due to the complexity of the project and the requirements for evaluating InfoMesh over a period of time, the researcher herself will first carry out a pilot study. Subsequently, two to four participants will take part in the study. Corresponding with the target population for the InfoMesh system, the chosen participants need to be computer users with a reasonable to high level of computer skills with relation to authoring and gathering documents, managing large amounts of electronic information, and using multiple personal computing devices (such as desktops, laptops and PDAs).

C.2.3 METHODOLOGY

The study will consist of a sequence of learning, exploratory and assessment tasks for evaluating participant understanding and use of InfoMesh (as a simplified implementation of the Pervasive Personal Information Spaces model). The study

aims to consider real world use of InfoMesh remotely over a period of time, with participants using InfoMesh on their own computers. Consequently several remote evaluation methods (Castillo, 2002), including the Experience Sampling Method (Consolvo and Walker, 2003) will be used in carrying out the study and collecting data.

The study has the following segments:

- 1) Introduction: Introduction to the study and InfoMesh, and InfoMesh installation and set-up.
- 2) Learning, exploration and training: Background questionnaire, learning tasks focused around a web-based InfoMesh tutorial and related video demonstrations, and exploratory tasks using an example set of activities and views.
- 3) Assessment: Instructions for using InfoMesh regularly for several user activities for two weeks. Data collection consists of intermittent questionnaires on user activity, interaction, views and preferences, as well as a final questionnaire and interview.

The learning and exploration segment is carried out early on in a single session, before the assessment segment, which continues for the two-week period. The final questionnaire and interview complete the evaluation.

The study data will be compiled from the study's questionnaires and interviews. The InfoMesh system has been extended to provide an interactive workbook and manage a study evaluation component for the study. The former presents or links to major study questionnaires and learning materials, whereas the latter employs remote evaluation methods to capture InfoMesh usage details and generate questionnaires for sampling user experience.

INTRODUCTION

At the start of the study, the participants will be asked to read the consent form and the bill of rights sheet either in person or over the phone. The evaluator will go over the purpose of the study with them and what it consists of, explaining that they will need to complete several tasks on their desktop computer or laptop for two weeks, work through a participant workbook and tutorials, and answer several questionnaires. After this, the participant will be asked to sign the consent forms. The evaluator will then proceed to explain that answers to questionnaires and

application-generated data will be recorded as far as that is acceptable to the participant by the InfoMesh application and sent to the evaluator. The evaluator will also inform the participant that the InfoMesh prototypes are the central focus of the study and not themselves, and that they should carry out the activities for the study in a way that is comfortable and usual for them. The participants will also be informed that they can opt out from the study at any time.

Participants will be asked to install InfoMesh on their chosen computers using the installation files and instructions provided to them. They will then be asked to perform a simple test to check if InfoMesh is set up properly.

LEARNING, EXPLORATION AND TRAINING

In the learning segment, InfoMesh will bring up a background questionnaire to gather details about participant daily device and information use. Participants are then asked to take a web-based tutorial on using InfoMesh, that presents details on starting up InfoMesh, creating and using activities and views, interpreting view elements, and using the various options and FlexTools features. Video demonstrations of InfoMesh will illustrate topics in the tutorial. The tutorial and video demos, as well as some further help documentation, will be accessible to the participant at any time during the study, from within the InfoMesh application itself.

Subsequently, participants are given several exploratory tasks to help orient and train them in using InfoMesh through personas and example activities. These activities and corresponding views can be used to explore specific features, manipulate and navigate the views, as well as look up information. The exploratory tasks also seek to familiarise users with various aspects of InfoMesh, encouraging their use in the following study segment.

ASSESSMENT

The assessment segment of the investigation forms the chief part of the study. Participants will be instructed to use InfoMesh regularly on their chosen device for one or more activities for two weeks, freely making use of various InfoMesh views, navigation options and FlexTools features. During this period, intermittent questionnaires will gather information on user activity, InfoMesh use and perspectives.

C.2.4 USER STUDY ENVIRONMENT AND EQUIPMENT REQUIREMENTS

Potential users would primarily make use of the InfoMesh system on their personal desktop computers at home, office or similar environment, or on the go when using InfoMesh on their PDAs and laptops. For evaluating long-term use of selected InfoMesh functionality (specifically of the desktop version of InfoMesh), participants will be asked to use InfoMesh on their main desktop computer (running Windows XP Pro). This set-up considers the everyday environment of use for predominantly the fixed location example of InfoMesh use. Both the *Composer* and *Presenter* applications that make up the InfoMesh system, their supporting programming environments (e.g. JRE 1.4.2), and application data will be installed on participant computers.

Physical artefacts and support material employed for the user study will include InfoMesh tutorials, exploratory activity snaps, video demonstrations and user guide, as well as interview material and an interactive participant workbook that is incorporated into the InfoMesh application. The workbook will link up to the exploratory and learning materials, provide the study instructions and generate questionnaires at regular intervals according to a sampling method.

C.2.5 DATA COLLECTION AND EVALUATION MEASURES

The long-term study aims to evaluate InfoMesh use remotely over a period of time, with participants using InfoMesh on their own computers. Hence the study plan incorporates several remote evaluation methods, including the Experience Sampling Method (Consolvo and Walker, 2003) for regularly querying InfoMesh usage and user experience. A preliminary investigation would review these methods for function and appropriateness.

Data will be collected and evaluated largely using questionnaires and participant generated data. Next to the background questionnaire, the learning, exploration and assessment segments are each followed by a brief questionnaire to gather participant interpretations, thoughts on use and interaction, reactions and preferences. A final questionnaire and interview give insight into how participants compare their folder views to their InfoMesh visualisations, and what their final views and thoughts are on InfoMesh, its use, issues, and interaction experience. (The interview would either take place face-to-face or over the phone.)

Furthermore, at given intervals of use (such as every hour) during the assessment segment of the study, InfoMesh presents a use-oriented questionnaire according to the Experience Sampling Method. The questionnaire's focus rests on the user's current activity, feature use, issues, thoughts and preference details. At the time these experience-sampling questionnaires are triggered, InfoMesh will also take a snapshot of the InfoMesh view in use.

The InfoMesh system's data collection component stores user responses to the various questionnaires while also logging and storing all of the quantitative background data for the study. This background data essentially consists of hours of application use, a listing of the activities and views created, features accessed, feature access frequency, navigation use, navigation feature access frequency, as well as data for use of markers, annotations, colour-coding and item grouping. The actual InfoMesh activities, views and data generated by the participant are also collected together. All of the collected data will be stored as specific data files in the InfoMesh application folder. In the actual field study, participants can email these files to the evaluator on completing the InfoMesh evaluation.

Responses to the questionnaires in the field study and the usage data logged by InfoMesh will help gather and clarify the following information:

- Participant understanding of the concepts underlying InfoMesh and InfoMesh views.
- Details of how participants explored and interpreted the views (as pertaining to the scenarios of use and activity snaps) provided by InfoMesh.
- Participant interaction with InfoMesh and its use, with notes on any issues or errors encountered by the participants during the study.
- Commentary on how participants compared views of their documents as provided by InfoMesh and as provided by current hierarchical folder views.
- Participant views on InfoMesh, and by extension, Pervasive Personal Information Spaces. These views would encompass InfoMesh features, use and the InfoMesh interaction experience, especially in providing access to personal information while supporting high-level activities and users' work context.

The evaluator will carry out several tasks for the study, which include:

- Explaining the study, tasks and evaluative tools to the participants at the start, and encouraging them to freely give their comments, share their ideas and ask questions whenever necessary.
- Recording and collating information from the study's tasks, interviews and questionnaires, as well as participant's comments.

C.3 CONSIDERING INFOMESH LONG-TERM USE

A preliminary investigation served as a pilot study to assess the study feasibility and plan for a longitudinal study on InfoMesh. The investigation aimed to give an initial assessment of InfoMesh long-term use focusing specifically on the desktop prototype, while reviewing and refining the study procedures, training material and remote evaluation methods. The investigation considered the study questions by reviewing the study materials, looking over InfoMesh learning tools, exploring and interacting with InfoMesh, and reflecting on its use over the set period of time. From this perspective, the pilot investigation may add to the findings from the former studies by shedding some light on InfoMesh real world use, and more particularly, help prepare for a future long-term field study.

The author conducted the preliminary investigation by using the InfoMesh prototype on a single personal desktop in support of a leisure writing activity over a week's time. As such, the investigation emphasised InfoMesh interaction experience and the flexible views paradigm. The pilot investigation followed the sequence of learning, exploratory and assessment tasks that look at InfoMesh comprehension and use, skimming over the introductory segment aimed to introduce participants to the study.

C.3.1 OBSERVATIONS AND DISCUSSION

The preliminary investigation helped to assess the plan for a longitudinal study and judge the robustness of the current InfoMesh prototype in view of its deployment for a long-term study. The investigation also showed which aspects of InfoMesh use could be covered and evaluated in the proposed field study. Simultaneously, InfoMesh use for a leisure activity provided some insight into the strengths and weaknesses of InfoMesh and the interaction experience it offered. This insight underscored and expanded on many of the conclusions drawn from

the earlier studies. (The investigation and its conclusions are summarised in section 7.3 of the thesis.)

STUDY ASSESSMENT

Reviewing the instructional material, remote evaluation methods and InfoMesh robustness in the investigation highlighted many changes that would be necessary before carrying out a longitudinal field study. The review also showed that many of the issues presented earlier on regarding the immediate feasibility of long-term study were justified to an extent. Consequently, the review supported the choices for limiting the investigation to a single device and the study period to at most a couple of weeks.

The learning tools of tutorials and video demonstrations, though useful, could be insufficient to give participants immediate confidence in using the InfoMesh prototype. A face-to-face session encompassing both the learning and exploration study segments would better deal with participant questions and uncertainties. Another solution would be to allow participants to contact the evaluator with questions during their learning and exploration phases to ease them into InfoMesh use. In both cases, their questions and problems would then help fill gaps in the instructional material, and in the latter case, also determine any serious runtime errors that might occur.

The remote evaluation methods seemed largely appropriate, however some issues became apparent during the investigation. One issue was the length of the main questionnaires, as users will have to type out their answers. Another important consideration is the interval time for issuing the experience sampling questionnaires. In the author's use of InfoMesh, hour-long intervals were too long as her activities were leisure-related and usually carried out for shorter spells of time. Other users might select time-consuming activities like research or project work, where interruptions every hour may be too often. One solution would be to set the intervals to 30 minutes, with user options to lengthen the intervals during long work periods. The data collection through InfoMesh also ran into some difficulty. Taking screenshots at the time of an interval questionnaire did not always capture the user's InfoMesh view correctly. Additionally the study may benefit from InfoMesh tracking both its own use by participants as well as the use of the folder system for carrying out the activity work.

InfoMesh use over the week unearthed a number of issues that could be quite problematic for evaluating long-term use. One major issue was encountered on the last day of the investigation. The JVM essentially ran out of memory during a longer session of activity work on a map view in InfoMesh, resulting in a fatal error that made InfoMesh unresponsive. The system was forcibly shut down. InfoMesh restarted all right, however the problem is serious and was previously thought corrected by increasing the heap space available to the JVM and restricting the information structures in InfoMesh. Two other issues lie with tracking web-browsing activity. The component application geared towards tracking web activity picks up pop-up pages and other secondary pages, but more importantly, crashes infrequently during heavy activity due to some synchronisation problems between the component and InfoMesh Presenter in accessing web history details. This leads to a flurry of errors from the component application that derails InfoMesh use. Consequently, the component application was intermittently turned off during use. Another issue lies with the Windows OS messages indicating file modifications. From time to time messages arrive for files that have not been accessed or modified directly by the user, which are then entered into the view.

There are some other glitches in the system such as timing issues, which irregularly provide incorrect document thumbnails for view items, drag-and-drop problems in the work view, and timeline navigator positioning inconsistencies. Some of these glitches however are more correctable than the previous problems. Still, the investigation left doubts about InfoMesh robustness at this point for supporting long-term use, especially one that incorporated multiple devices and/or longer periods of use (more than two weeks for example).

Finally, the investigation showed that only some aspects of InfoMesh can be reasonably evaluated in the space of a few weeks when used in support of a few activities. Specifically, views such as the overview, work view or even the social view may not get much use. However, the activity and map views as well as numerous InfoMesh supporting features (e.g. navigation and other toolbar options, annotations and colour coding, and FlexTools options such as view swapping, filters and queries) could be evaluated more extensively. These aspects of InfoMesh together would still provide insight into the user's interaction experience with flexible views and contextual information retrieval. By extension,

participants could then say something of their views on Pervasive Personal Information Spaces, as well as ubiquitous access to their information through systems like InfoMesh.

INFOMESH ASSESSMENT

The author employed the desktop InfoMesh prototype to support a recent leisure-related activity. Before presenting an assessment of InfoMesh use and interaction, some background details are described here regarding her usual device use and information management behaviour. These details can have a bearing on her views of InfoMesh use. Similar details are also collected for participants in the complete study.

Background

The author makes use of several personal devices: two desktops each in a different country, a laptop that travels with her on long and short trips (as well as some brief visits to local places to carry out work while waiting for something else), and a PDA that also comes along with her on many trips and outings. Other peripheral devices include USB-drives and external hard-drives. Her devices run Windows XP Pro, and her PDA, Windows Mobile 5.

Content on her desktops and laptop overlap, with her most up-to-date personal work currently on her laptop (this changes with the type of work) and her home-related material on her desktop. Content on these devices ranges from research work and related material to various leisure and personal interest activities (hobbies, creative interests and ideas), multi-media (music and photos), archives of past work, and various home and personal management material (finance, recipes, schedules and travel).

She uses Microsoft Outlook to manage all her tasks, synchronised between her laptop, current desktop and PDA in part. Her PDA largely keeps track of important tasks, e-books and shopping lists, and is used for jotting down some notes on the go. She makes use of a home network (wired and wireless), though the PDA is disconnected due the slow nature of the wireless downloads. Windows' offline synchronisation manager deals with keeping the current desktop and laptop synchronised. However, the process can sometimes be problematic,

especially when synchronising with the second desktop (the manager only handles two devices at a time) or due to network connection and re-connection issues.

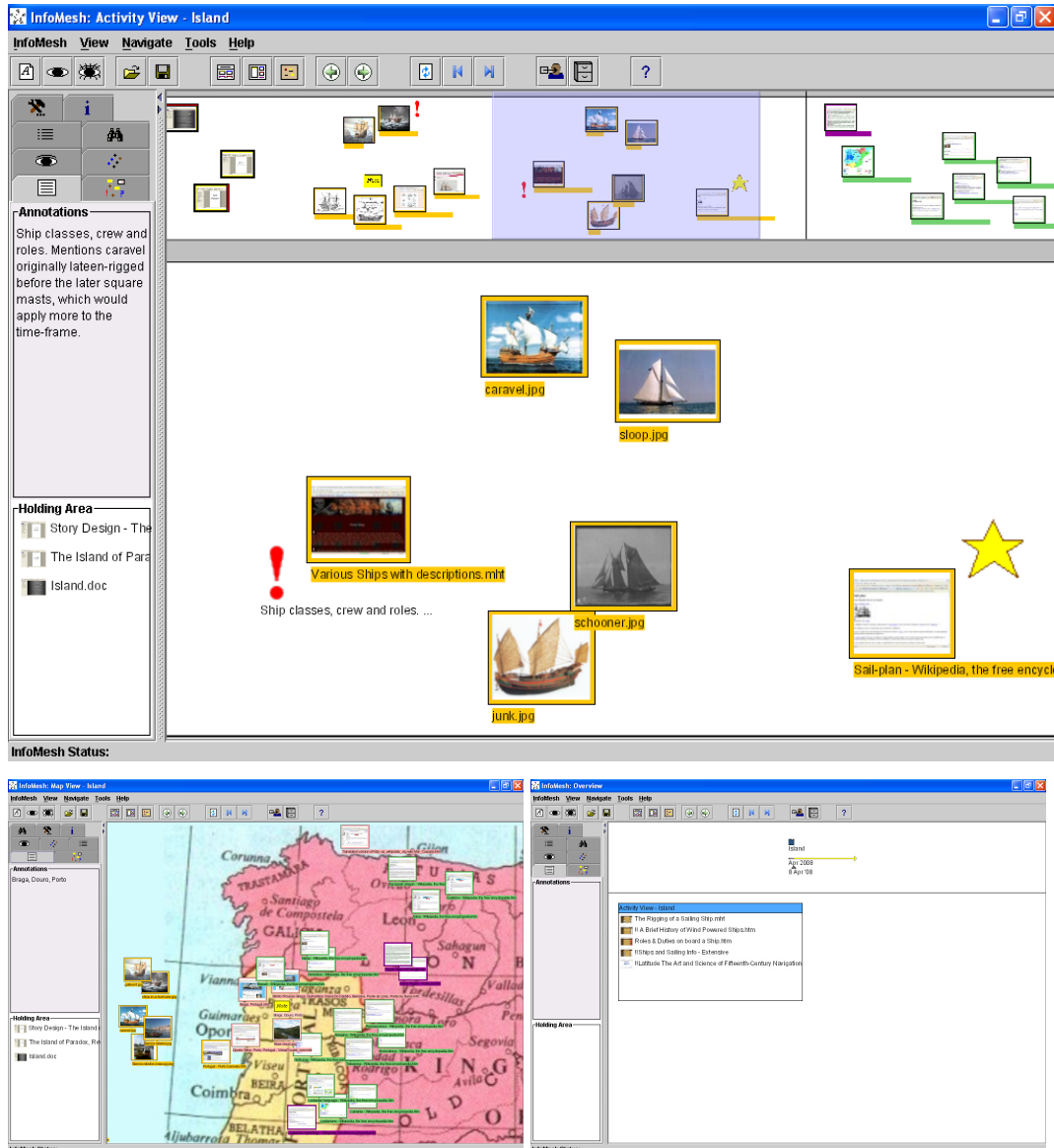


Figure C-1: Activity view, map view and overview screenshots for 'Island' activity work

Activity details

The author used InfoMesh in support of a creative writing activity ('Island'), which included some background research for the story, the story design and some writing elements. She has gone through a few similar writing activities in the past. She made use of an activity view to track her research, design and writing, and a corresponding map view to relate some of the articles of interest and ideas to the relevant locality on a map (see Figure C-1). She did not use the social view or

work view, and rarely used the overview and notice board. The overview was effectively only used as a launch pad.

With regard to InfoMesh features, she made use of item annotations, view markers, item grouping and colour coding to enrich the activity space. She used a historic map of a region (downloaded from the Internet) and used the map to position items on the map view. She further used the pan and zoom functionality for her usual view navigation and less frequently the toolbar navigation options (such as the refresh, view beginning and view end options). The FlexTools annotations panel and filter/query option were used often, while she used the view swapping option to go between the two views for the activity from time to time. She also flagged several important documents (the story and story design documents) for quick access to them via the FlexTools' holding area.

InfoMesh views and interaction

The perspectives offered now relate back to the questions the study aims to answer relating to InfoMesh views and interaction. They also describe some of the usability issues encountered.

Both activity and map views were easy to adopt, as the meaning they lent the work was apparent. Working with time and location did not require much effort in interpretation, however, in the case of the map view, required some initial effort in adding a map and positioning items on the view. Both the views worked very well with the activity, because of the inherent context-based information associations as well as annotation-based information associations (e.g. colour coding, item annotations and grouping). View switching supported resuming work and tracking activity progress through the activity view, and making sense of information through the associations in both the activity and map views.

InfoMesh interaction felt largely natural. However, panning across the activity could take much more effort and time with larger activities. The 'Island' activity ran into more than a hundred files in the week of use (and would have included many more if the component application tracking the web browsing were active full-time). As the activity view space is spread out, the panning from one end of the view to the other slowly became cumbersome. This can largely be blamed on the style of view panning offered which consists of figuratively grabbing the workspace to move it. A better mode can employ a technique similar to the auto

scrolling accessible through a click on the mouse wheel, where the horizontal position and nearness of the mouse pointer in relation to the scroll icon could indicate the speed and direction of movement in the view. Zooming in and out on the map view came naturally and benefited the interaction as well as the perspective on the documents in the view. Consequently, zooming was used more frequently in the map view, but rarely in the activity view. Similarly panning was used a little less in the map view. The navigation options were mostly useful to go to the end or beginning of the activity view.

Thumbnails in the views offered a number of clues about the documents, and so seemed more useful to have than leaving documents as simply icons or titles in the view (e.g. in the 'Island' activity the thumbnails show among others visits to a several Wikipedia pages on ships and downloaded ship images in one session and later on visits to different cities on a tourism site). When looking specifically at recently visited items, the thumbnails triggered document recognition. When revisiting an activity after a long time, they were not as useful, except with images and striking or important documents.

InfoMesh use naturally brought a number of issues and room for improvements to light, beyond the issues mentioned earlier in relation to InfoMesh robustness. Some of these highlighted participant responses from the first two studies. Multiple selection of items for dragging, annotating or colour-coding would be really useful, or rather, quite a necessary feature. It would also be highly useful to add existing files into a new view. In the 'Island' activity, a couple of files already existed with notes on the story and story design, which would have been nice to add into the new view upon creating the activity in InfoMesh. Similarly, in creating a map view based on an existing populated activity view, it would be useful to provide users with the option of selecting all or selecting only specific items from the activity for inclusion in the new view. In the 'Island' activity, only one third of the activity documents were of importance in the map view. The rest simply cluttered the space. These were moved to the side of the view, but that action required time and effort. Finally, the activity and map view for the 'Island' activity showed that InfoMesh needs to keep track of view notes and markers for each of the views separately. As the views are contextually different, a view note or marker in the activity view had little meaning in the map view.

In some situations, researching an idea on the WWW results in a lot of visited pages, some of which are unnecessary and so clutter the view. When some unwanted web pages are added to the view, InfoMesh should provide a way of deleting these from the activity trail. The effort taken to review and delete them might be lessened in providing an option to selectively add only pages of interest. Perhaps creating an InfoMesh toolbar for browsers would have its benefits. It can have options for switching monitoring on or off, or selectively adding pages to the current activity. Similarly, options for deleting items from a single view are also useful even if they leave gaps in the information trail.

In other situations, the trail created by browsing the web was really useful, as there is little effort in tracking the many pages of interest. This was advantageous when researching some historic ships for the 'Island' activity, as the trail kept track of the meaningful web page titles and important pages could be annotated with notes. These titles and annotations could then be queried in the view later on. Presently, automated tracking is largely limited to tracking user information trails for activity views. However, this feature would give much added benefit when expanded to include email and contact tracking, and some intelligence in classifying items or associating them to people, locations and information sources. Furthermore, for long activities, an implementation of the envisioned query view and interactive query list (where each query result takes the user to the result's view context) would be imperative. A change for the filter view might include contracting the result view. Otherwise large, filtered activity views would once again be harder to navigate.

InfoMesh currently does not register files simply accessed from the hard-drive (due to problems in the Windows OS file access messages). On using InfoMesh though, it became quite clear that for proper use InfoMesh does need to find a work-around for this situation. An activity's information trail would miss the nuances that come from accessing previously saved documents for purely reviewing that information. In the 'Island' activity, some saved web pages were later revisited while working on the story design. The information associations created in that session were however incomplete, as InfoMesh could not add those pages that were simply 'accessed' rather than created or modified.

InfoMesh use and the interaction experience

There were several things that stood out in using InfoMesh to interact with information in the ‘Island’ activity. They mostly centred on contextual access and retrieval, using time and location contexts as well as personalised annotations and activity spaces:

- **Time:** Time through the activity view afforded a way to see the changing research phases (from ships, to legends and regions, and back to ships and navigation) and offered a more effortless way of resuming the ‘Island’ activity when the mood called for it, as the previous work state was preserved in the activity space. The view also allowed time-based retrieval of information. One example involved revisiting web searches on a topic (such as barges from a specific time period and related pictures) that were largely carried out in a particular session and therefore formed a short trail of related information within the activity view. The view’s automatic tracking of work as an information trail was definitely an agreeable feature.
- **Location:** The map view allowed articles to be associated with region, both with respect to information about the locality as well as its legends and history, which was very useful as a reference to figure out which pieces of information could be incorporated in the story for the main region of interest. The map view could also be uniquely adapted to the work and the user’s preference. Articles on ships or the fantasy island were for example associated with ocean space. Articles of the least importance could be moved to a corner of the map.
- **Personal information associations:** Item annotations helped track important snippets embedded in articles and spontaneous ideas, which are otherwise hard to track and which now could be queried at any time. Item grouping as well as colour coding helped relate articles on similar topics easily within a session. Markers performed a variety of functions, including locating a fantasy island on the map, adding notes to areas on the map or to groups of items on the workspace to indicate keywords, and even indicating the research phases or the changing direction of the work.

Associative or contextual retrieval proved to be quite useful, especially as it relied on tracking small relationships and notes that together formed a visual picture of the work. These relationship clues allowed easy interpretation of the information

and a natural way of re-finding material. Time was automatically tracked along with thumbnail views. Other workspace annotations took a little effort, perhaps as much or even less effort than in previous activities, where some of those annotations were written down in the story design document, but where the direct associations with various articles were lost. The map view took the most effort, especially in positioning items on the map. InfoMesh first adds these items to the view in a linear fashion. If they are not positioned early on, the meaning of the documents may be harder to remember. When items are not positioned for a whole session, the map view just seems cluttered and item arrangement would require more effort. For the ‘Island’ activity, however, the effort in positioning items was rewarded by the ease of re-finding items for quick reference, especially after some time (even a couple of days), by which time the importance or use of a document or its regional associations are difficult to recall.

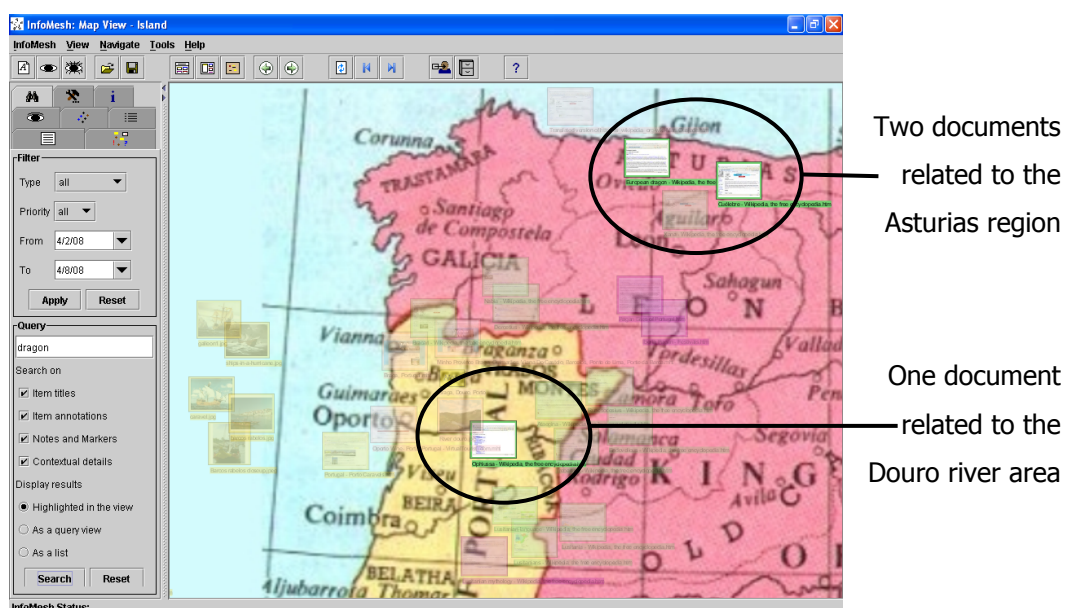


Figure C-2: Contextual query using the ‘Island’ activity’s map view

In previous writing activities, retrieving reference material that related to a particular piece of information or an idea was often frustrating, especially due to the lack of this type of contextual retrieval. Often the query does not relate to a specific searchable word; sometimes the query is to find a specific term or myth. (One example involved locating the legend of ‘Xanas’ and which region they were associated with. Another search was for the exact name of a type of barge ‘barcos rabelos’ mentioned in one of the visited web sites.) Searching on the personal annotations using the query tool was therefore quite effective as

interesting story elements or items were noted down earlier with the articles and the view workspaces. The query tool was especially useful as the context was preserved: the context imparted meaning to the search results and other nearby, relevant material could be perused at the same time. (An example search for a previously encountered dragon tale located the main legend beyond the region of interest. However, the search also brought up another reference to a people in the region of interest itself, namely near the Douro river. Hence the context of the search immediately showed which of the material might or might not be applicable to the location of the story. Figure C-2 provides a screenshot of this query.) The little effort required in annotating items of interest was therefore often warranted in the 'Island' activity for the time and frustration it saved in making sense of and retrieving information. Previously some of these notes were written on paper or in the story design document, or often, partly and incompletely stowed away into memory. Searching within files would be of much added benefit though to the query tool.

Different activities might benefit to a varying extent from contextual retrieval and personalised activity spaces. However, InfoMesh use with the 'Island' activity hinted at a lot of potential and possibilities. The interaction experience was distinctly personalised, which was both refreshing and useful. There is a shift in perception from simply *documents* to a web of personalised and associated *information*. This information encompasses documents, annotations, colour and information associations through contexts of use and multifarious information trails. Hence, the information truly forms an information space rather than a document collection.

Activities like writing a book or article, carrying out research, maintaining a digital scrapbook, or exploring hobbies would especially benefit from tracking work in this personalised way. Other activities like updating financial information or downloading music would not necessarily. Similarly not all activities would require the same extent of personalisation of the information space through annotations and colour coding. The richness of the annotated space would relate to the complexity and depth of the activity, and so for example, previous research work and creative endeavours would benefit more from these personalised annotations.

Archiving information with these personalised views also seems very promising. Other similar creative writing work from the past can only be looked at as a listing of folders. The folder categories are descriptive, but further details such as the development of work or document associations beyond the folder category are lost. Interesting stories, information and past ideas are embedded inside myriad documents and web pages, and are difficult to recall or retrieve. The personalised activity spaces (offering multiple contextual views and contextual query tools) can therefore conceivably be more meaningful and helpful when revisiting or resuming an (older) activity.

Comparing InfoMesh views with hierarchical folder views

Several things were apparent when comparing hierarchical listings of information with InfoMesh views. Quick access to remembered documents (i.e. remembered article titles and folder locations) was definitely easy through folder views kept for the 'Island' activity. InfoMesh on the other hand would slow down that access if items were not accessed during the last session, present in the holding area or at a remembered location on a view (such as articles about the 'Azores' islands which are positioned by their location on the map).

The folder system allowed broad categorisations of the material (in folders such as 'Legends', 'Porto Braga Maps' and 'Ships – images'), which provide a useful starting point in retrieving information. However these folders only came into place mid-research, as is often the case, when the main folder became large and unmanageable. As the information coming in was hard to classify initially, there was no real way to create the categorisations then. (Furthermore, bookmarks needed to be copied repeatedly across from the bookmarks folder to associate them specifically with work on the 'Island' activity.) Even now, the categorisations are vague, as material in the folders often covers other categories as well. The 'Legends' folder for example contains information about legends, but also of regions, peoples and history. Some articles on local history are also there in the 'Porto Braga Maps' folder. In reality, this folder set-up would be re-organised periodically to categorise and make sense of the content. Other more clearly defined work may not require as much (if any) re-organisation.

Categorisation of work as an activity and tracking the work as an information trail negated the need to re-organise the work habitually, except for of course, adding

annotations and positioning items on the map. Adding similar contextual details and annotations in the folder view would take more effort (e.g. through naming schemes and separate ‘notes’ documents). The folder system’s properties feature does not work for certain files such as bookmarks and is also quite cumbersome. On the other hand, large amounts of content can create busy activity spaces in InfoMesh, especially cluttered map views. The map view for ‘Island’ was created after a while, when multiple region-based articles were read. InfoMesh generated the view with all of the activity’s documents, which needed to be re-positioned to create the location-associations. For some activities like ‘Island’ this work creates a more memorable part of the activity-interaction itself, triggering ideas and interpretation of the material. However for many or even most other activities, re-organising a map view might be simply undesirable effort.

Two other major benefits to the ‘Island’ activity folder listings include the ability to scan down a (sorted) list of documents to roughly see the documents in a category and the ability to search for text within the files. On the other hand, associative or contextual retrieval is difficult and much of the work context is simply unavailable. This makes resuming an activity and making sense of an older activity harder. Whereas the InfoMesh views for ‘Island’ make immediate sense even now (several months after the activity was tracked). The activity view picks up where the last session finished, and the map view promptly shows all the region-associations for the articles. The visual, contextual nature of the views vividly triggers the memory of the groundwork done for the activity work, as well as the elements important to the writing content for the activity (e.g. regions and ships of interest to the story, and legends and other items of interest which were colour-coded and associated with regions).

Overall, the visual presentation of information in InfoMesh (with context and annotations) does retain far more personalised and meaningful information about current and previous work than hierarchical listings of files. The hierarchical folders provide a simpler, cleaner organisation of the material. Each system would suit certain types of activities better than the other would. However, there was a distinct benefit during this investigation in having access to both InfoMesh and folder views. They were both used in carrying out the activity, and certainly complemented each other. As remarked by several participants in the last study, integrating the two could exploit the strengths of both and build further on their

synergy: an example application would include filtering InfoMesh views based on listings in a selected folder. This idea of integration was explored in both the former research into TimeSpace and the current InfoMesh design phases to some extent, but warrants a much closer look.

Pervasive Personal Information Spaces

On the whole, InfoMesh use made the unexplored and missing aspects of personalised interaction experience and information retrieval by associations or context far more obvious in the current-day information-interaction scenario for supporting user activities. For example, the first thing that comes to mind in remembering the 'Island' activity work now is the map view, which triggers a number of story element associations. The 'Island' activity work underscored that user information-interaction is essentially personal and unique to the user. Contextual details and information associations further impart abundant meaning to user work. Ultimately, seamless integration and automatic tracking of information would also be a great benefit in the ubiquitous computing landscape, both for reducing user effort and tackling information overload (especially where the associations between pieces of information are lost).

In the 'Island' activity example, having access to the material and its entire context through the other devices (specifically both desktops and laptops) would help in resuming the activity whenever and wherever. As a leisure activity, it is only infrequently re-visited and then too for brief spells of time. So previous work states, contexts, contextual queries and information associations form an important reminding function. Sudden opportunities of time would make access to the material through the laptop or PDA very useful, so that the work can be reviewed, opportunistic research carried out, and ideas noted down. The PDA would probably only be used to review some of the saved articles or add some notes.

InfoMesh use definitely made it clear that the system is not a replacement for the hierarchical folder views or vice versa. They both contain various elements that are essential to information-interaction, combining personalisation and organisation. However, it is clear that using simple hierarchical listings for viewing and accessing information is not sufficient to provide a more personalised interaction experience or support fluid ubiquitous access to personal information.

InfoMesh in its current prototype state is not the complete answer, but it offered an exciting array of possibilities to shift information-interaction more from managing and making sense of documents to simply carrying out activities whenever and wherever.

C.4 RECOMMENDATIONS FOR FUTURE INFOMESH DEVELOPMENT

InfoMesh user evaluation, through the two user studies and the preliminary investigation into long-term use, has revealed various usability issues as well as scope for improvement and expansion. Some of the usability issues were ameliorated through the various stages of InfoMesh development and user evaluation (as described in the sections and 6.3.4 and 7.2.4), whereas other issues required more time and/or inquiry before they could be addressed. In the short term, these issues can be tackled alongside InfoMesh robustness. In the medium and long term, InfoMesh can be extended with some of the user suggestions and many of the envisioned design ideas, which will help investigate Pervasive Personal Information Spaces further through the prototype system. Naturally a variety of user studies will also guide and evaluate these extensions.

In the short term, work on InfoMesh needs to examine and address the following usability issues among others. With respect to activities, InfoMesh should allow users to limit the kind and amount of information tracked (specifically for web browsing work), provide options for selectively deleting items and assigning items to other activities or views, let users add existing documents to new views, and decouple view notes and markers from the activity to associate them specifically to a view alone.

At the level of views, InfoMesh will need to support the selection of multiple items for manipulation, an improved work view, a better resolution for view content (e.g. thumbnails), notes and markers that present more of their text on the view space, view position indicator that shows the current position relative to the entire view space, birds-eye-view navigation support for social and map views, and mouse wheel scroll support as well as support for auto-scrolling.

In relation to FlexTools, marker positioning has to be improved with additional options for users to add their own markers to the system, several FlexTools and

context menu options need to be moved to the toolbar (such as swapping views or flagging items of importance), an interactive colour legend has to be added, and the diagramming tools designed early for marking views need to be updated to the 'View Markers' panel as well. The panels for 'System Settings and Preferences', 'Visualisation Options' and 'Information Settings' need to be completed and incorporated into InfoMesh. The query view and interactive query list options for the 'Query and Filter' panel, and the 'View Contexts' advanced view set-up also need to be finished.

Finally at the system level, work is necessary on the improving the 'open' dialog specification, providing activity and view selection options from the toolbar, printing views and annotations, and simplifying the use of the system's colour palette for colour coding items.

In the medium term, a number of ideas can be explored, designed and implemented. In improving InfoMesh robustness, care must be taken with the redesign and debugging of the system to prevent memory errors, a better option needs to be researched for tracking web browsing activity, and InfoMesh will need to register information access properly alongside information creation and modification. Several other issues and ideas are worthy of attention, including

- considering how to best present information sharing in a diagrammatic style for social views or how to let users apply their preferred style,
- changing view detail according to zoom levels, developing an InfoMesh toolbar for web browsers,
- developing InfoMesh view sharing and archiving in detail and studying their benefits,
- developing InfoMesh combined context views and advanced views further,
- ironing out information integration across devices, and providing a usb-drive based InfoMesh update option for non-networked computers,
- extending information and context tracking to include emails and task management tools, and extracting relevant contextual associations from all the information that is tracked,
- designing an InfoMesh meta-mode to support learning and provide contextual help,

- depicting action history by tracking and playing back information usage as a sequence of documents (e.g. large thumbnail views of the last work state for documents) and annotations,
- refining the InfoMesh ‘Activity Browser’ FlexTools panel in order to combine InfoMesh and hierarchical folder listings (where contexts and associations can potentially correspond to fields), and
- developing a simple interactive InfoMesh version for PDAs.

In the long term, InfoMesh can deepen the investigation into Pervasive Personal Information Spaces by studying and incorporating several ideas. As such the work would essentially aim to explore and add the many nuances that can affect the implicit meaning, usefulness and interaction experience offered by contextual, flexible views in the ubiquitous computing environment.

Building more sophisticated agents for tracking information usage and context, classifying information, and communicating and integrating information across devices, will make an enormous difference in reducing user effort and keeping InfoMesh complete. Automatically registering and incorporating more contextual details is central here, but only while it focuses on details that truly inform user work and aid recall, without adding to the information load (e.g. geographical locations or building locations can aid memory, whereas gaze tracking, gesture recognition or minute details of the situational context may overwhelm information that is useful for supporting work). A web component can potentially support viewing and sharing information trails online.

Overviews of the information space that support information exploration and discovery, views for mobile phones, as well as other interesting views (e.g. day stream, relationship and goal views) can be explored further to see how the early design ideas can be refined for inclusion in InfoMesh.

Among many other ideas, view sharing and social navigation, as well as incorporating secondary user devices (e.g. storage devices and information capture devices), all warrant further study. All of these aspects (e.g. agents, views, devices) help create a Pervasive Personal Information Space and can help offer a more natural, personalised and ubiquitous interaction with electronic information.

Naturally, a special emphasis will lie on a variety of user studies in the medium and long-term. A longitudinal field study is in order after refining and improving

InfoMesh with respect to some of the main usability issues, suggestions and supplementary design elements. A follow-up on the field study can capture user feedback on returning to their previous methods of viewing and accessing information. Other topical studies are also justified, such as user-subjective evaluation by using activity snaps in exploratory and comparative studies, an evaluation of a more interactive InfoMesh version for PDAs, a study examining user interaction and view preferences for Pervasive Personal Information Spaces, and an investigation into archiving and social navigation using InfoMesh views.

D. FUTURE VISIONS

This section presents an example of how Pervasive Personal Information Spaces can be expanded in the future and also provides some quick example applications of Pervasive Information Spaces.

D.1 PERVASIVE PERSONAL INFORMATION SPACES IN THE FUTURE

Chapter 3 (section 3.2.2) looked at the current computing environment and the Pervasive Personal Information Space solution to address some of its limitations within the constraints of current technology and feasibility. The near-future goal in establishing Pervasive Personal Information Spaces is to complete the shift in human computer and information interaction towards personalising the computing experience and allowing people to focus more on their actual activities and less on managing and making sense of their documents. Again, the persona Lisa is used to illustrate the solution.

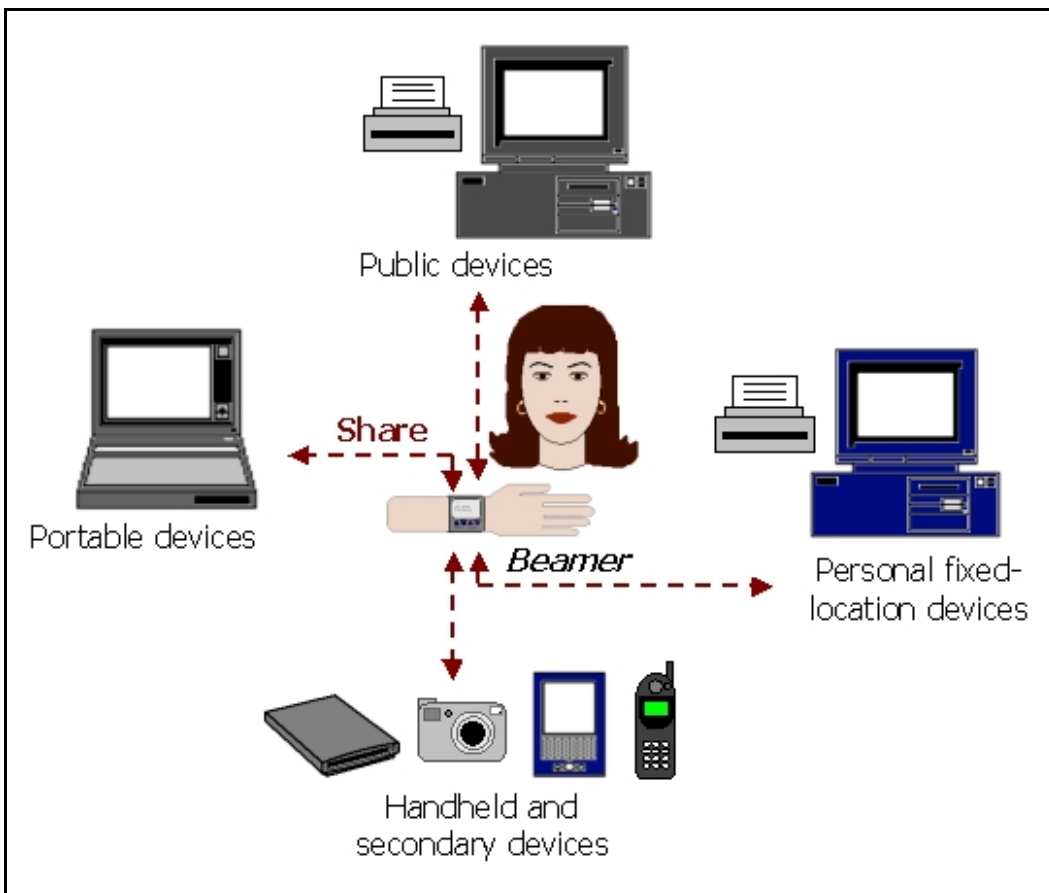


Figure D-1: Information sharing between Lisa's Beamer and devices accessed

In the future set-up, Lisa's Pervasive Personal Information Space comprises of the information registered and tracked on all her main and secondary computing devices. Her information space stretches out to incorporate her interaction with public devices as well. In this environment, Lisa's space may support both secure, networked transfer of information and information storage and transfer through a wearable device she carries with her at all time.

In this second case, the small wearable device (here envisioned as a device called *Beamer*), securely carries Lisa's entire, annotated information repository, registers her real-world and computer-supported activities' social and physical context, and transfers information between all of the devices that she interacts with. Consequently, the Beamer has large storage capabilities, fast and wireless information transfer options, and protocols and sensors for context registration (e.g. locations and other people). The Beamer also supports privacy and security settings with multiple pre-sets to model different use contexts (as with the Situational Faces metaphor reviewed in section 2.6.2), and identification protocols for personal devices and abstracted identities for basic use of public devices.

Information transfer and context registration using the Beamer happens largely behind the scenes, according to Lisa's changing activities, environment and device use. For example, when Lisa finishes her searches on the library computer, her Beamer copies across her search and result details, articles and electronic notes. When she then accesses her PDA, her Beamer updates the device immediately. Her results for the book locations she had noted down on the library computer are now available on the PDA as she walks through the library. At home, her Beamer updates her laptop with all the newly acquired documents and information, once Lisa sits down to work through the material. The Beamer also backs up Lisa's entire information repository onto her main device regularly. Anytime-anywhere-any context interaction is now truly at her fingertips. Figure D-1 shows Lisa's new device information sharing using the Beamer. (In this diagram, the Beamer is shown as a wearable wrist device. However, it can be any small or wearable device, which can be easily carried everywhere by the user. Other centralised or readily replicated information sharing solutions are also very possible for developing the future solution.)

Lisa's updated Pervasive Personal Information Space expands on previous views to provide further contextual views and multiple types of overviews, to suit

individual preferences and information behaviour. Hierarchical listings of information items are still in use, but are now incorporated with the visualisations to support contextual detail as well. Registered context now includes more people and locations of relevance, as location sensors and other people's Beamers communicate basic details. A certain level of application intelligence also allows Lisa's activity work to be classified and clustered across and within activities. Though Lisa's information management tasks have been minimised further, there are still certain information relationships and contextual detail that she would have to add to the views on her information space, as context registration by devices can only readily provide simple, objective details.

As before, Lisa can archive work as 'pictorial' activity trails that provide better understanding of past work than a listing of files alone. Similarly, she and others can share these activity visualisations and navigate shared interests using the detailed and vivid information trails previously discovered and explored by one another.

Lisa's expansive web of information - comprising of her activities, interests, information items, annotations, work context and information relationships - is with her everywhere, through all her activities and information interaction as her Pervasive Personal Information Space. It tracks, integrates and presents her work and essentially the story and evolution of her activities over her lifetime in rich, associative detail, supporting life-long learning and discovery.

D.2 PERVASIVE INFORMATION SPACE EXAMPLES

Pervasive Information Spaces can be developed for a variety of domains. Some example applications are as follows:

- Associating user information interaction across online medical and health resources, such as medical databases (e.g. www.webmd.com), health and nutrition sites (e.g. www.whfoods.com) and various health forums, which can be seen and linked as a related library of sites. Resources such as these provide information and support for many people learning about and managing aspects of their health. A Pervasive Information Space can keep track of the information accessed over time, written and read forum posts, with annotations and any personal medical information. As with many online

communities, discussing and sharing information is very common in the health forums. Consequently, keeping views and information trails as an ongoing reference, and sharing non-personal information trails online for informing new community members about a specific topic, can all be useful tools.

- Managing research review work through the visualisation and access of research article collections. User interaction in reviewing research can focus on tracking articles from different subject areas, finding key papers in a topic and bridge papers for specific categories and topics, tracking read and unread papers in the document space, and discovering new papers of interest within a set of topics. Here a Pervasive Information Space (next to providing ubiquitous access to the state of the work, the interaction and the changing information space) can for instance focus on flexible views that portray information and topic relationships, overviews for supporting browsing and information discovery, and annotations for searching and keeping track of read/unread or important papers.
- Tracking knowledge and group projects in a company's research and development department. Views and trails on this information space can together form the organisational memory. Goals in this domain may include managing tasks, responsibilities and results from team projects; tracking progress and making inferences about the work carried out; keeping track of organisational knowledge for sharing and discussing ideas and directions; and archiving material for review and reference. In this situation a Pervasive Information Space might provide ubiquitous, contextual views for managing work across branches and locations, viewing information according to team members, and tracking the changing directions and output of the research work. Privacy issues may require limiting access to specific individuals or offices, and keeping off-site access protected for security.
- Developing a Pervasive Information Spaces for medical practitioners that combines their research, research reviews, conferences and practical experience across information databases and resources. Information trails and views on this space can help track special cases, background information and notes of importance. These trails can provide personal and shared learning and reference tools, act as group memory, and support richer information queries.

- Creating a Pervasive Information Space for the home that encompasses the growing number and variety of devices in the domestic space. Information integration can shift from supporting work continuity to supporting information and activity continuity for leisure activities. Information access can then support real-world activity components, like reviewing a recipe, watching a movie, sharing ideas, having conversations, playing music, bringing up the day's schedule and so on from any device in an interactive and socially-oriented fashion, and track user activity for reference and reminding. These ideas encompass the appropriation of technology for 'non-tool' use, the shift to 'non-work' activities and context, and a focus on the 'non-worker' aspect of users as expressed in (Howard *et al.*, 2007).

There are many other examples possible from supporting 'expert' information trails and contextual views in digital libraries on community knowledge and resources to support learning and knowledge building, to hobby and shopping trails for personal interest and shopping sites in support of information sharing and social navigation online.